Advanced Modeling & Simulation (AMS) Seminar Series
NASA Ames Research Center, March 26th, 2026

ATA ENGINEERING, INC.

Using Anisotropic Mesh Adaptation to Automate Computation of Multifidelity Aerodynamic Databases for Flight Dynamics

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ATA Engineering, Inc.

Darren Luke
Air Force Research Laboratory



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Outline

- **Main Topic: Automating Aerodynamic Databases for Flight Dynamics [A]**
  1. Executive Summary
  2. Methods
     a) Automated Process Description
     b) Demonstration Case
     c) Automated CFD Methods and Representative Results
     d) Multifidelity Surrogate Modeling and Automatic Sample Selection
  3. Results
     a) LF Surrogate Model
     b) MF Surrogate Model
  4. Conclusions
- **Supplement Topic: Computing Stability and Control Derivatives with Adapted Meshes [B]**
  1. Using generalized aerodynamic force method
  2. Benefits: include damping derivatives in surrogate, gradient-enhanced surrogates

A. Ricciardi, A.P., V. Harris, N. Gibbons, E. Blades, and D. Luke. "Using Anisotropic Mesh Adaptation to Automate Computation of Multifidelity Aerodynamic Databases for Flight-Dynamic Analysis." AIAA SciTech, January 2026. https://doi.org/10.2514/6.2026-0495

B. Ricciardi, A.P., J. Trout, E. Blades, and D. Luke. "Direct Computation of Stability and Control Derivatives with Respect to Static, Dynamic, and Unsteady Variables." AIAA SciTech, January 2026. https://doi.org/10.2514/6.2026-2285

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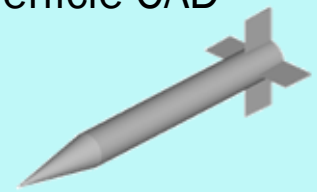
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Objective: A New Paradigm for Creating Flight-Dynamics Databases

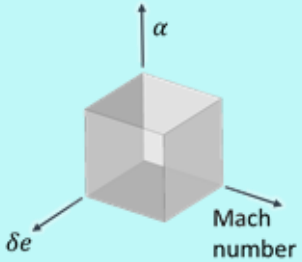
CAD and operating range is the input – A surrogate aerodynamic model is the output

User Inputs

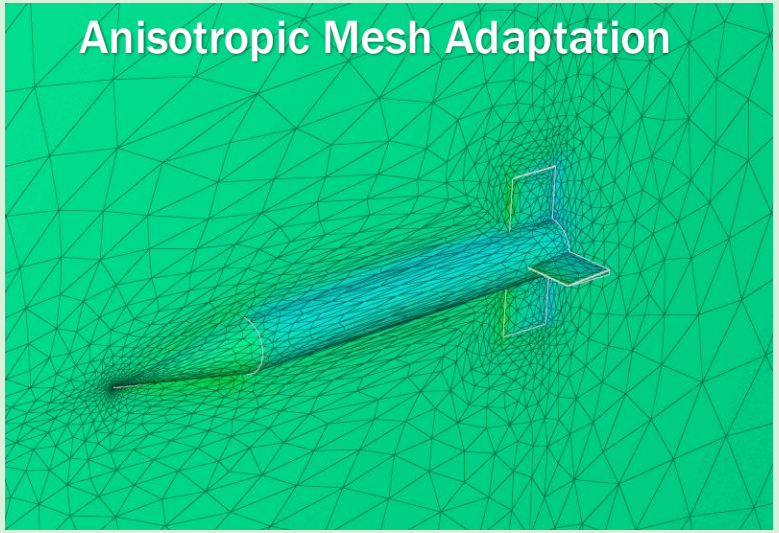
Vehicle CAD



Operating Range



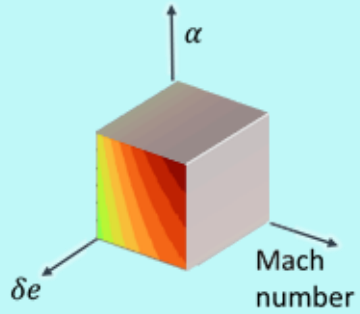
Automated Process



Autonomous multifidelity analysis
Autonomous training sample selection

Output

Surrogate Aerodynamic Model for Flight Dynamics



$$\boldsymbol{f}_{aero} = \boldsymbol{f}_{aero}(states)$$

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Overcoming Labor and Technical Challenges Using State-of-the-Art Methods

- **Labor Challenge** – substantial human effort by expert analysts is required to:
  1. Ensure mesh quality and solution accuracy for CFD modeling of complex flows
  2. Select aerodynamic solution points that adequately resolve vehicle characteristics for flight-dynamics analysis
- **Technical Challenges:**
  1. Mainstream tools for mesh adaptation are generally limited to isotropic refinement and exclude boundary layer regions
  2. Automated selection of aerodynamic solution points favors an active learning approach based on quantified surrogate uncertainty
- **ATA Objective** – create high-quality aerodynamic surrogates automatically
- **Progress:**
  1. Adaptation algorithms have been formulated in recent years for **anisotropic adaptation** of the entire fluid domain, including **viscous boundary layers**.*
  2. Multifidelity machine learning (ML) methods enable high-fidelity surrogate representation and automatic datapoint selection

*Alauzet, F., and L. Frazza. "3D RANS Anisotropic Mesh Adaptation on the High-Lift Version of NASA Common Research Model." AIAA Aviation 2019 Forum.
*Balan, A., et al. "A Review and Comparison of Error Estimators for Anisotropic Mesh Adaptation for Flow Simulations." *Computers & Fluids* 234, 2022.

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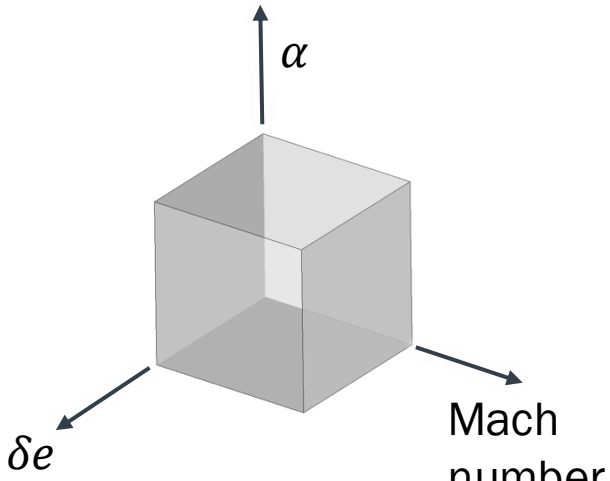
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Automated Process Description

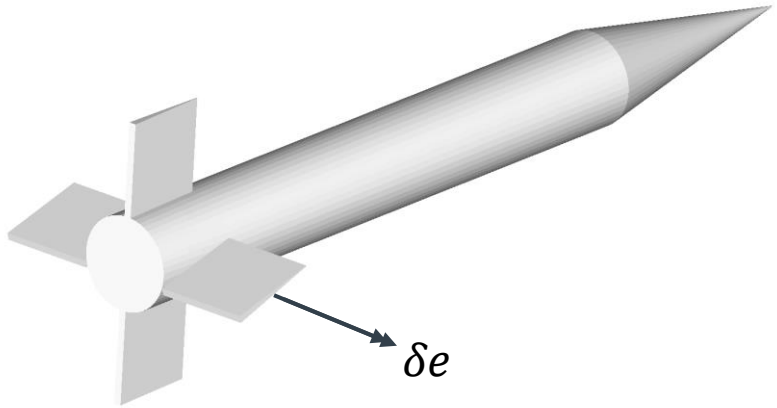
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User Inputs

1. Operating Range

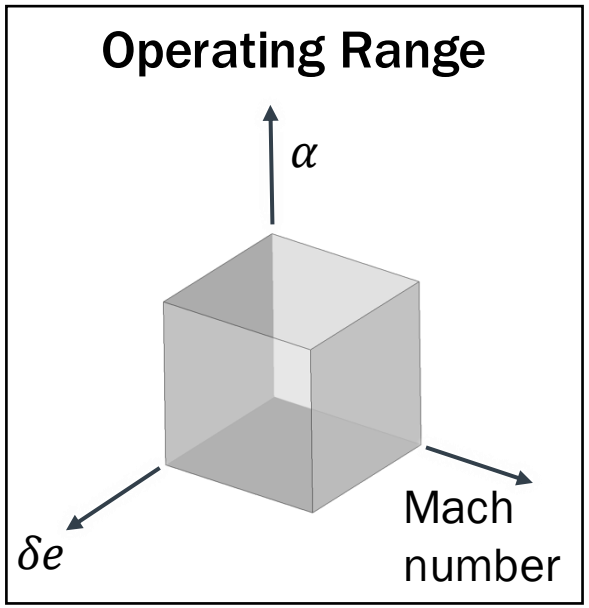


2. Parameterized Vehicle CAD



Example geometric parameter

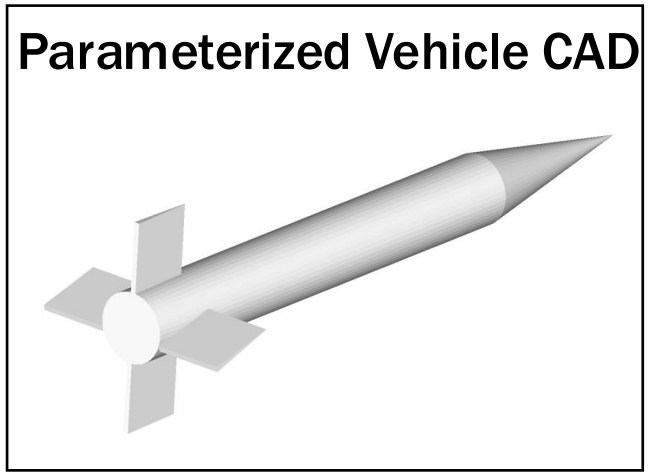
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Initial Training Sample Selection

Uniformly random points in normalized operating range

Geometric parameters (e.g., δe)



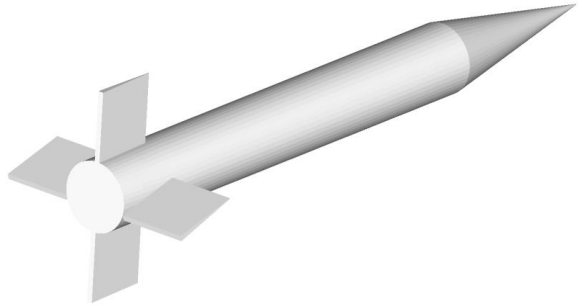
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Initial Training Sample Selection

Uniformly random points in normalized operating range

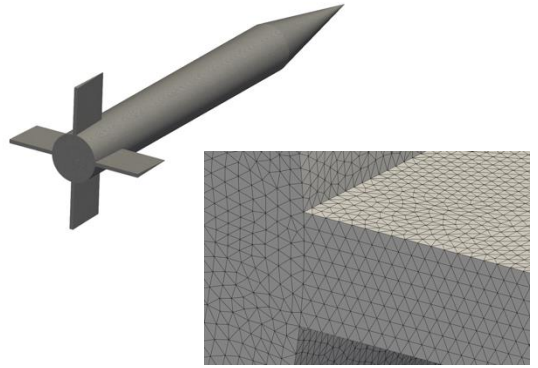
Geometric parameters (e.g., δe)

Parameterized Vehicle CAD

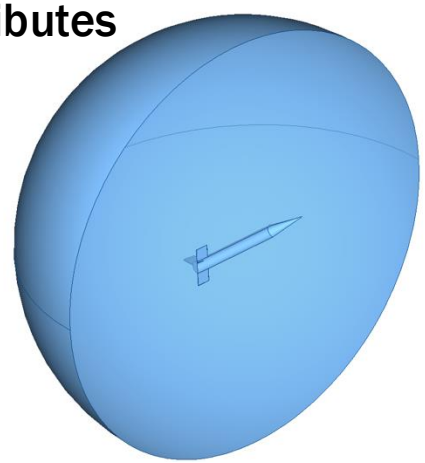


Automated Model Export

Surface Mesh

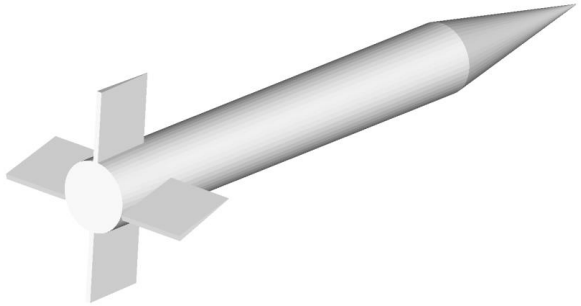


Domain CAD Geometry & Attributes



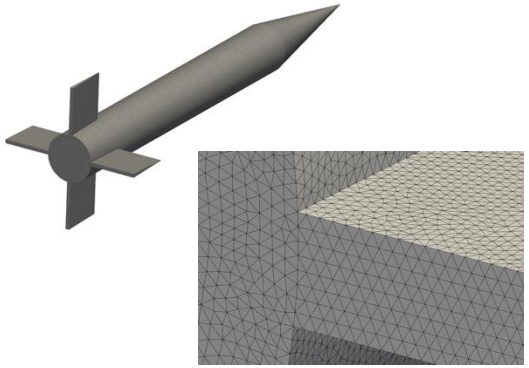
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Parameterized Vehicle CAD

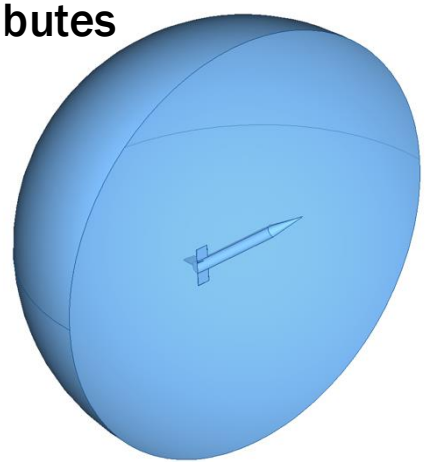


Automated Model Export

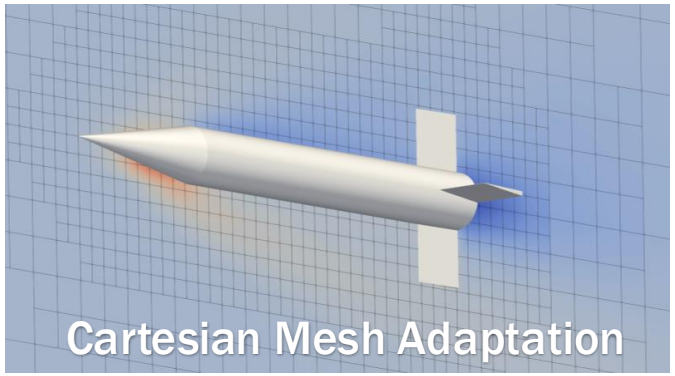
Surface Mesh



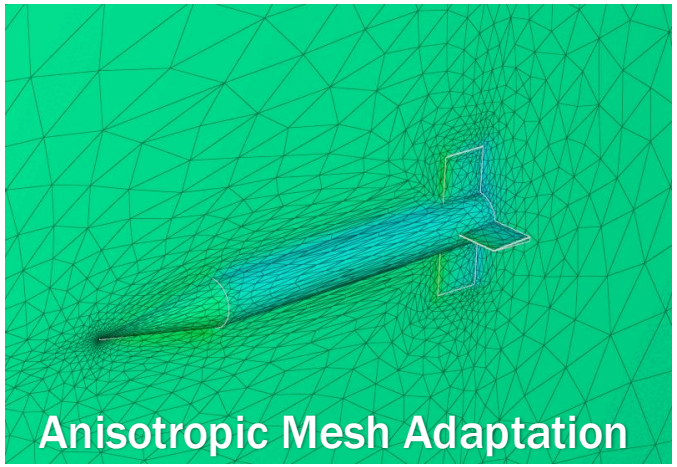
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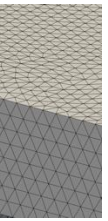
Automated Inviscid Analysis



Automated RANS Analysis



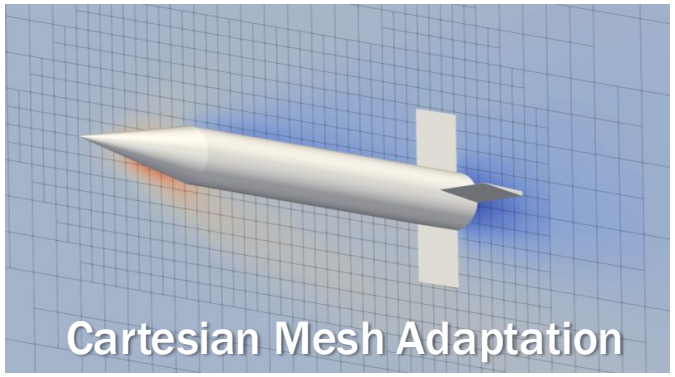
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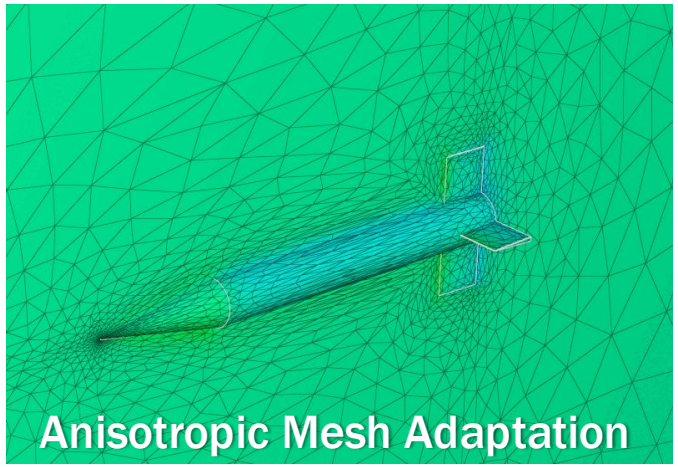
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Automated Inviscid Analysis



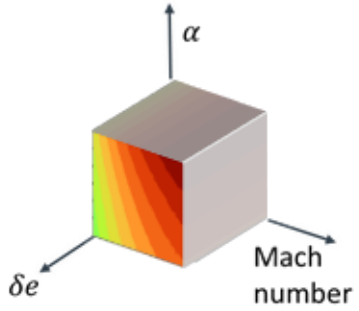
Automated RANS Analysis



Low-Fidelity (LF) Training Data

High-Fidelity (HF) Training Data

Multifidelity Surrogate



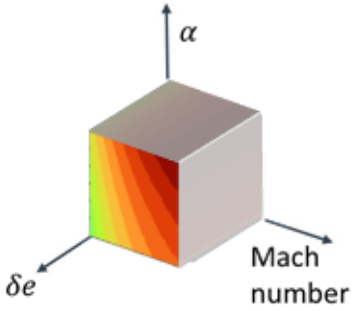
$$\boldsymbol{f}_{aero} = \boldsymbol{f}_{aero}(states)$$

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Low-Fidelity (LF) Training Data

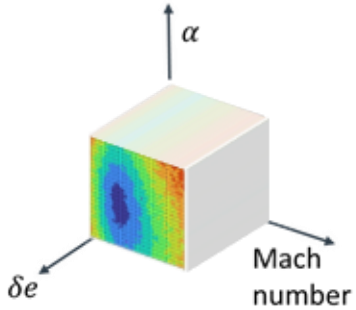
High-Fidelity (HF) Training Data

Multifidelity Surrogate



$$\boldsymbol{f}_{aero} = \boldsymbol{f}_{aero}(states)$$

Uncertainty Quantification



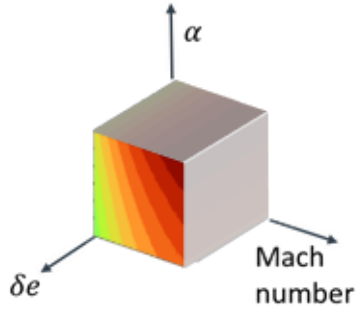
Acceptable uncertainty?

Excess uncertainty?

New training sample points

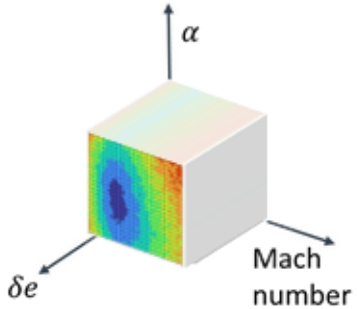
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Multifidelity Surrogate



$$\boldsymbol{f}_{aero} = \boldsymbol{f}_{aero}(states)$$

Uncertainty Quantification



Acceptable uncertainty?

Deploy Surrogate Model



Excess uncertainty?

New training sample points

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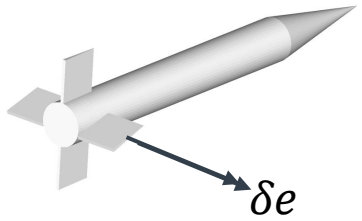
Demonstration Case

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Demonstration Case

*Army-Navy Finner (ANF)**

Geometry



Parameters & Operating Range

Parameter	Range
Mach number	1.5–5
Angle of attack (α)	0°–10°
Fin deflection (δe)	-5°– 5°

Surrogate Outputs

$$\frac{L}{D}, C_x, C_z, C_m$$

Input/output data for longitudinal flight dynamics model

* Dupuis, D., "Aeroballistic Range and Wind Tunnel Tests of the Basic Finner Reference Projectile from Subsonic to High Supersonic Velocities," Technical Memorandum 2002-136. Defense Research Establishment Valcartier, Quebec, Canada, 2002.

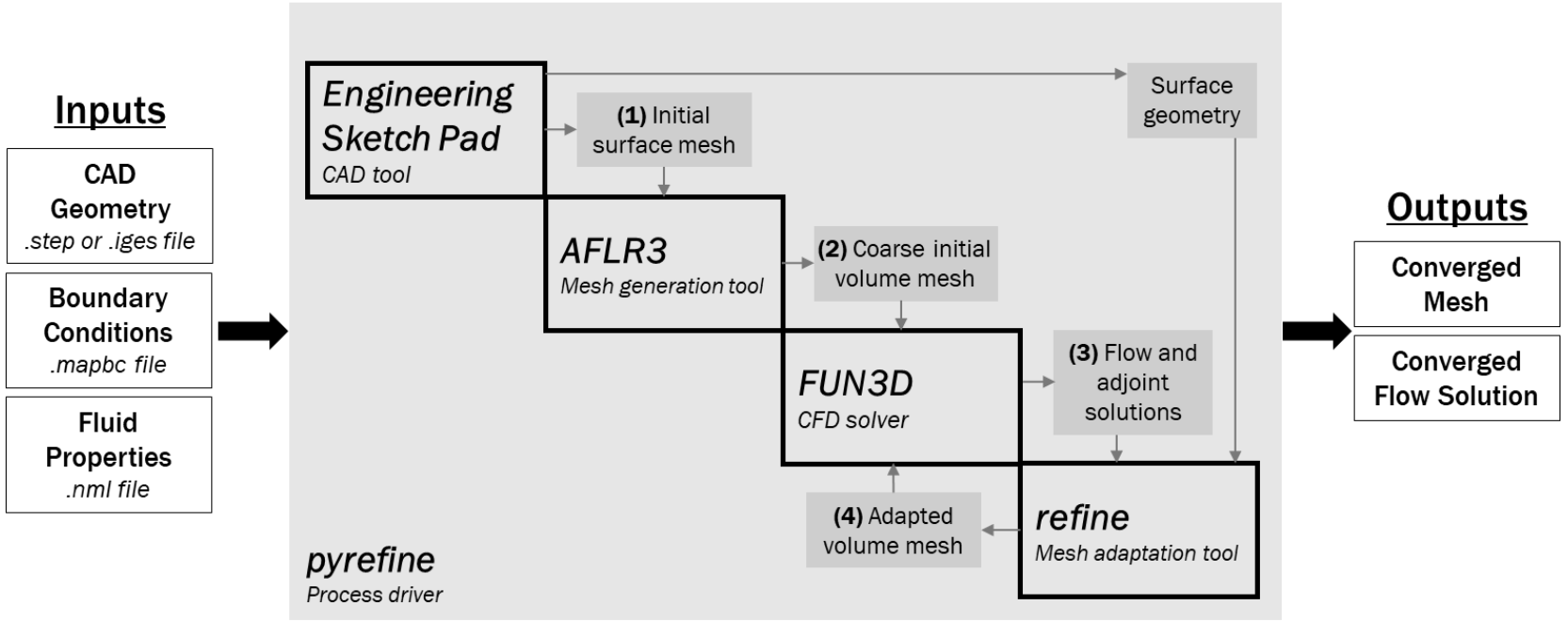
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Automated CFD Methods and Representative Results

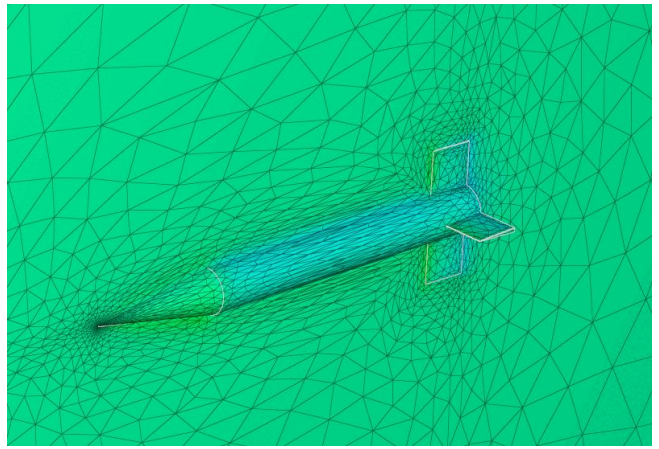
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RANS Analysis with Anisotropic Mesh Adaptation

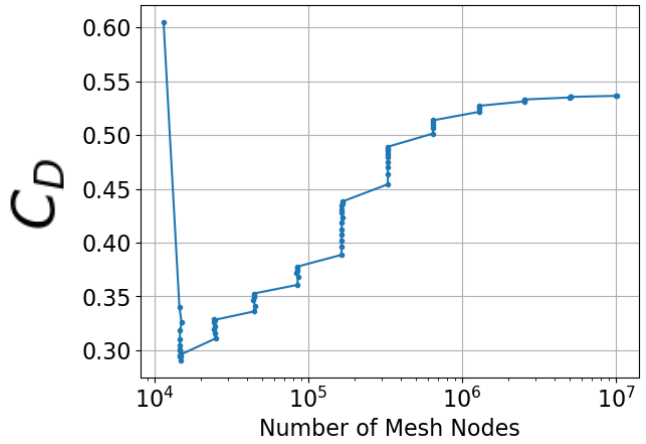
State-of-the-art process converges reliably and provides high-fidelity training data



Mesh Adaptation



Output Convergence



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Inviscid Analysis with Cartesian Mesh Adaptation

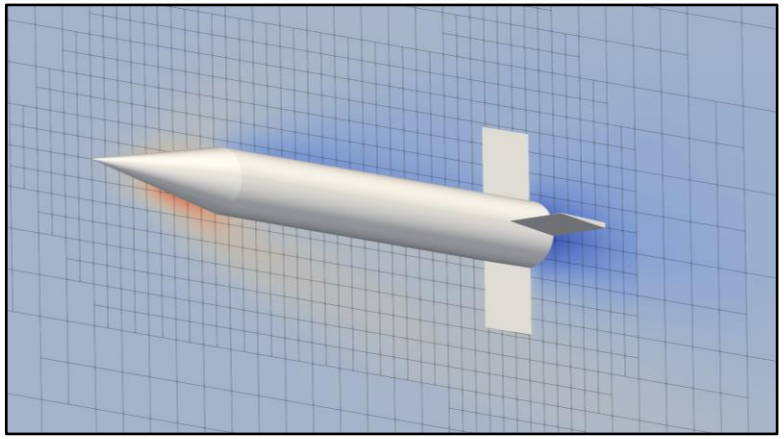
Cart3D converges reliably and provides inviscid training data

Average Runtime Per Solution Point	
FUN3D RANS with AMA	~2800 CPU Hours
FUN3D Inviscid with AMA	~1500 CPU Hours
Cart3D with Adaptation	**~25 CPU Hours**

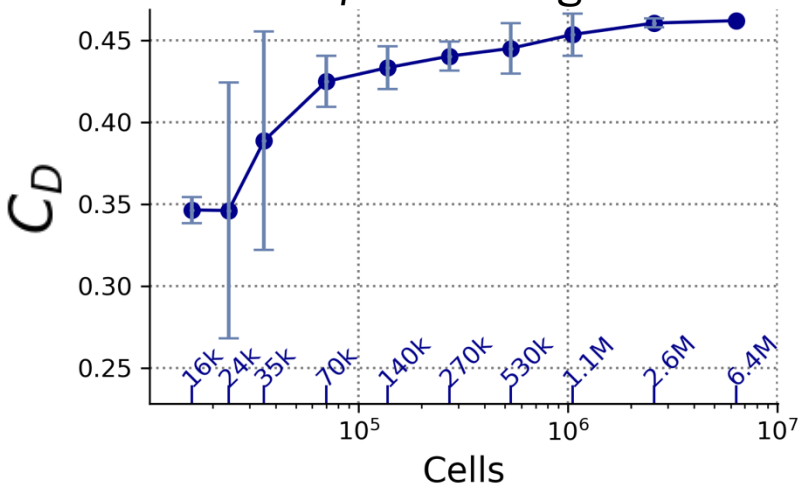
Cart3D delivers:

- 100x runtime improvement compared to FUN3D RANS
- 60x runtime improvement compared to FUN3D Inviscid

Mesh Adaptation



Output Convergence



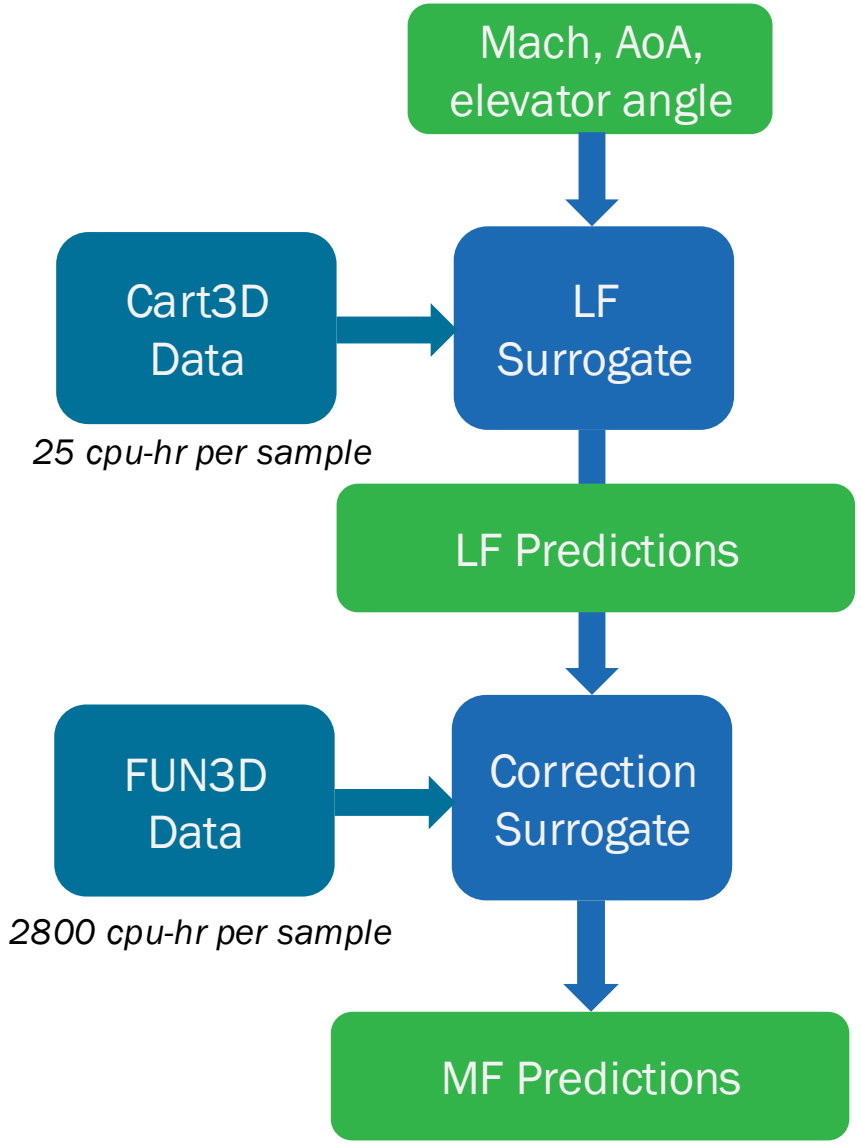
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Multifidelity Surrogate Modeling and Automatic Sample Selection

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ML Surrogate Modeling Approach

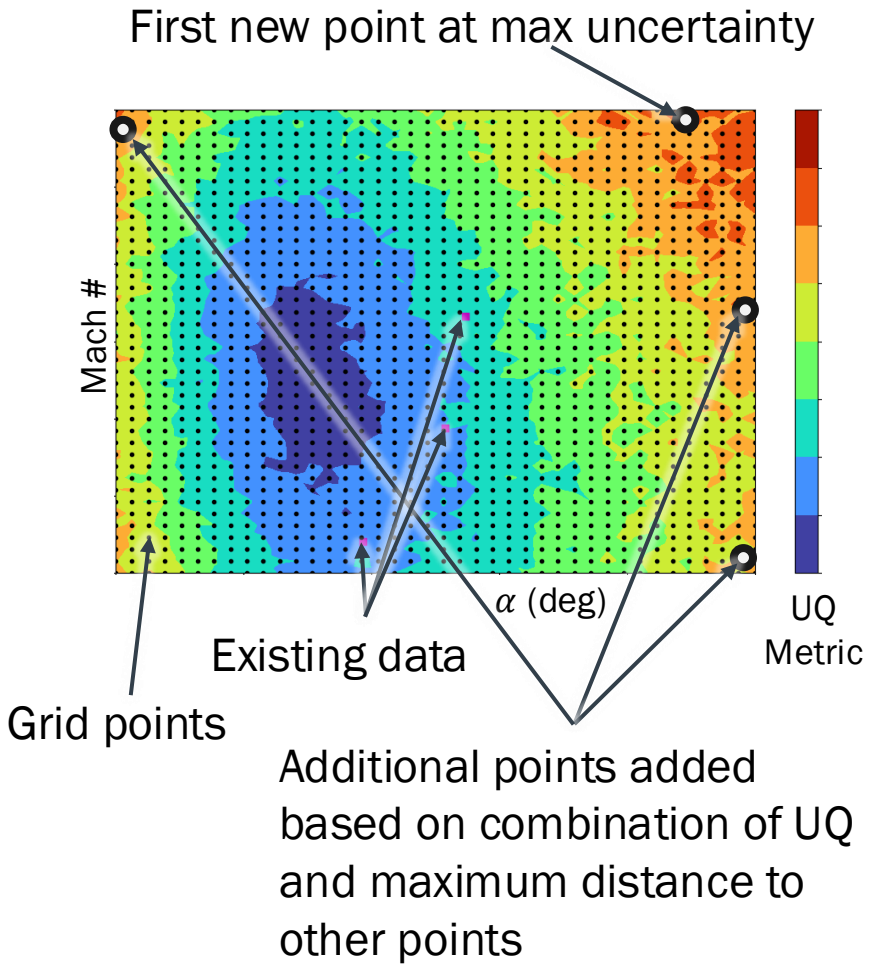
- Objectives:
  1. Prediction accuracy approaching FUN3D RANS analysis
  2. Rapid network predictions (< 1 second)
  3. Mitigate network training cost compared to baseline methods of expansive HF data sampling
- The Multifidelity surrogate layers two neural networks:
  1. The base neural network is a low fidelity (LF) surrogate trained to replicate Cart3D predictions
  2. The second neural network learns the correction between the LF surrogate predictions and the FUN3D data
- Network uncertainty quantification (UQ) is performed using Monte Carlo dropout and other methods to derive confidence intervals.



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Autonomous Process for Selecting Training Datapoints

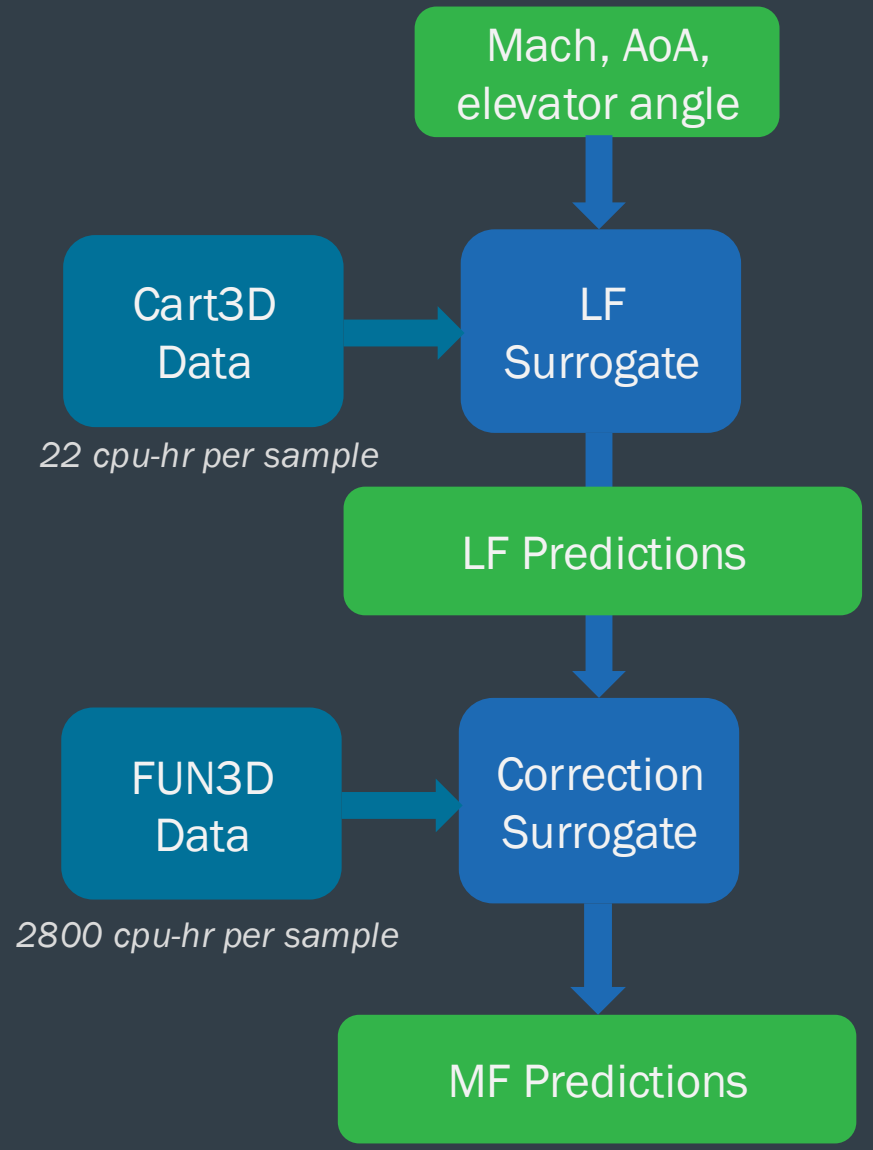
- Active learning – an algorithm determines which new data points would provide the most new information to the existing model
- Uncertainty sampling – add a point at the location where the current model is most uncertain, then retrain the model with the new data and repeat
- For efficiency, our method uses a combination of UQ and distance from existing points to identify multiple new data points simultaneously:
  1. Divide entire input space into grid
  2. Calculate uncertainty across all grid points
  3. Locate point of highest uncertainty and add it to list of existing data points
  4. For each of the remaining grid points, calculate the minimum distance to the existing data points
  5. Combine the distance score and UQ score at each grid point and add the highest-scoring grid point to the existing data points
  6. Repeat steps 4-5 to generate a list of new data points for consideration
- Weighting of distance score and UQ score is determined by user



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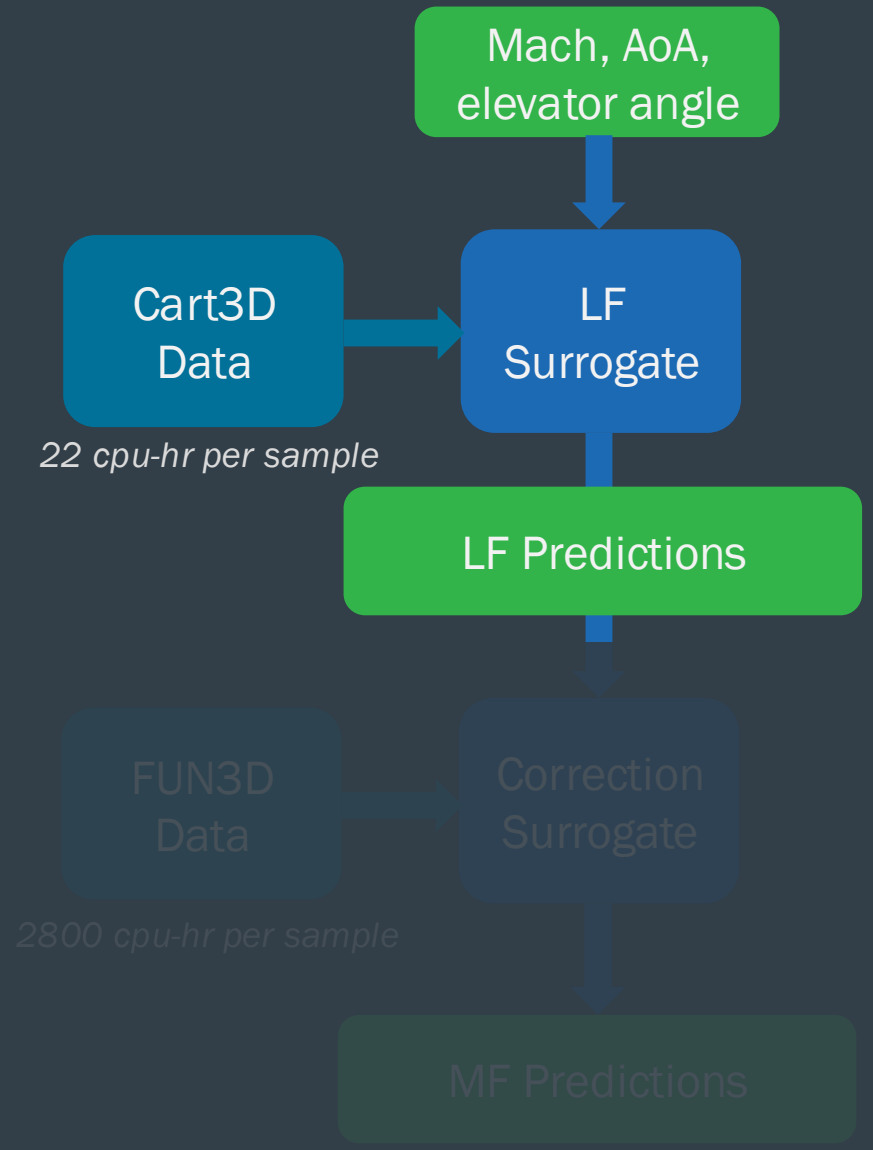
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Surrogate Modeling Results



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LF Surrogate Modeling Results

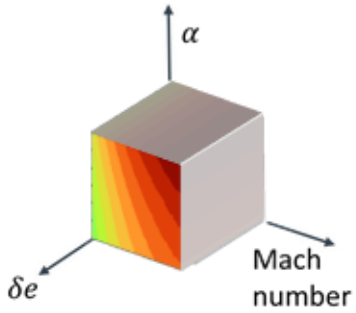


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LF Surrogate Prediction

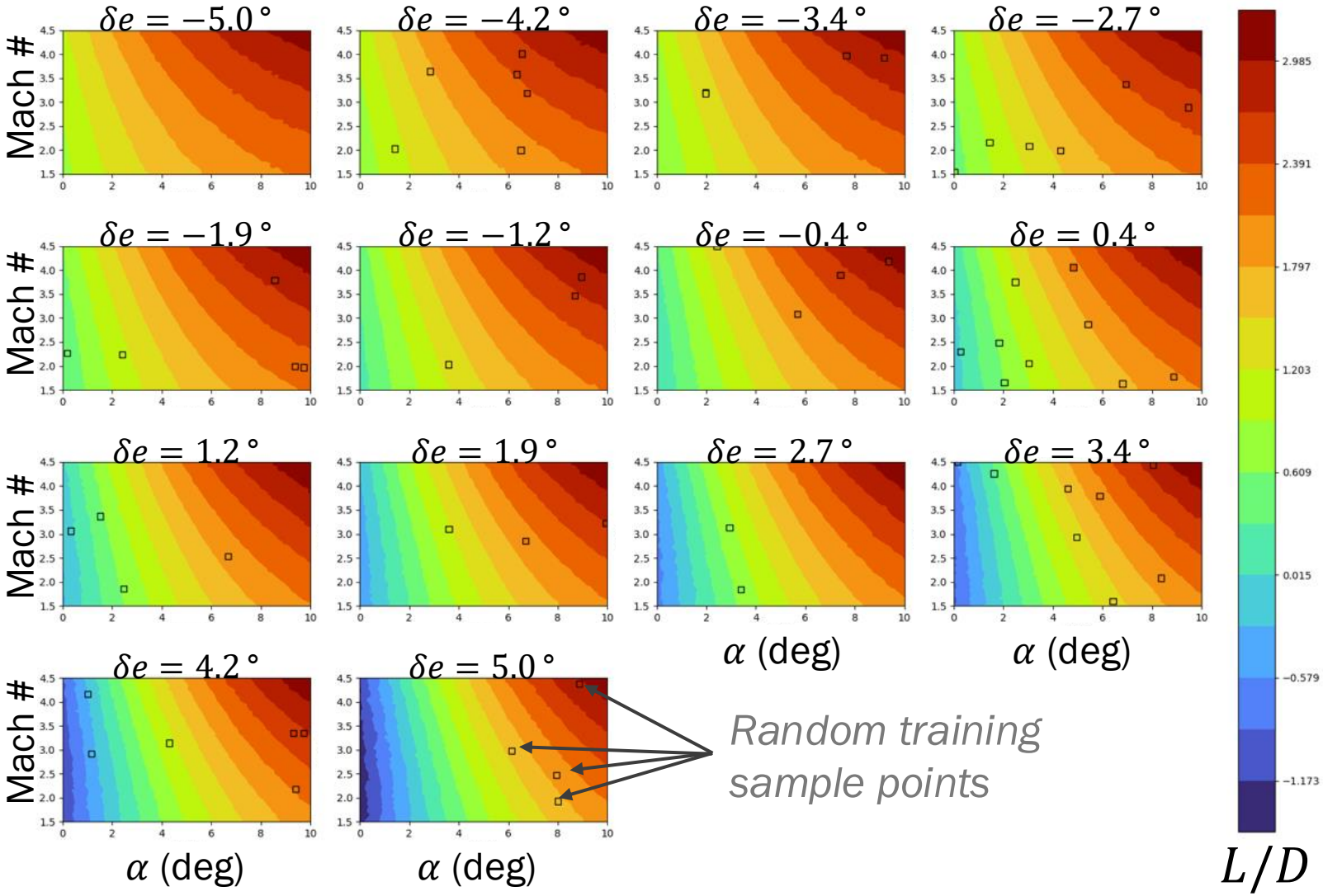
Visualized Across the Multi-Dimensional Parameter Space

Surrogate Aerodynamic Model for Flight Dynamics



$$\boldsymbol{f}_{aero} = \boldsymbol{f}_{aero}(states)$$

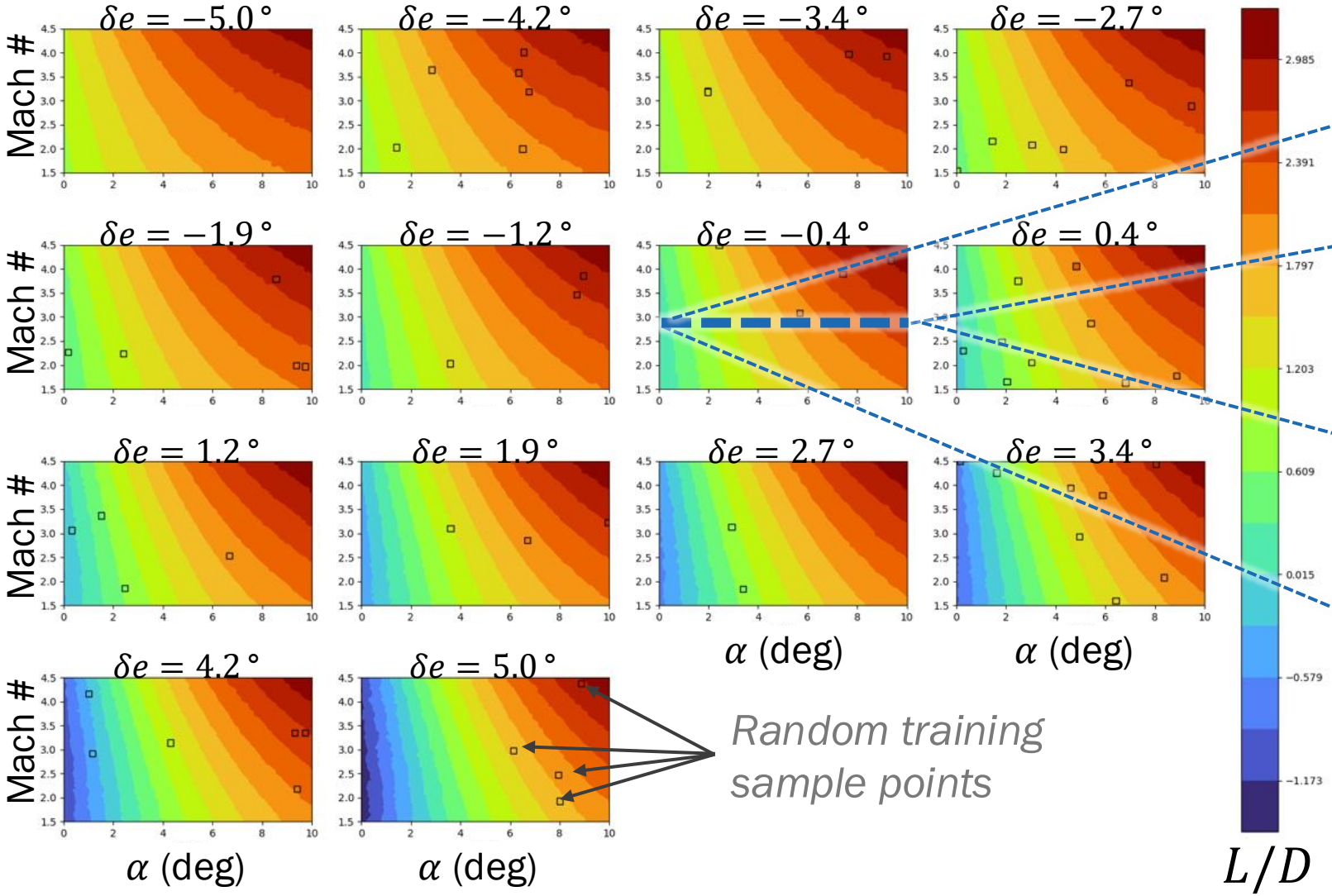
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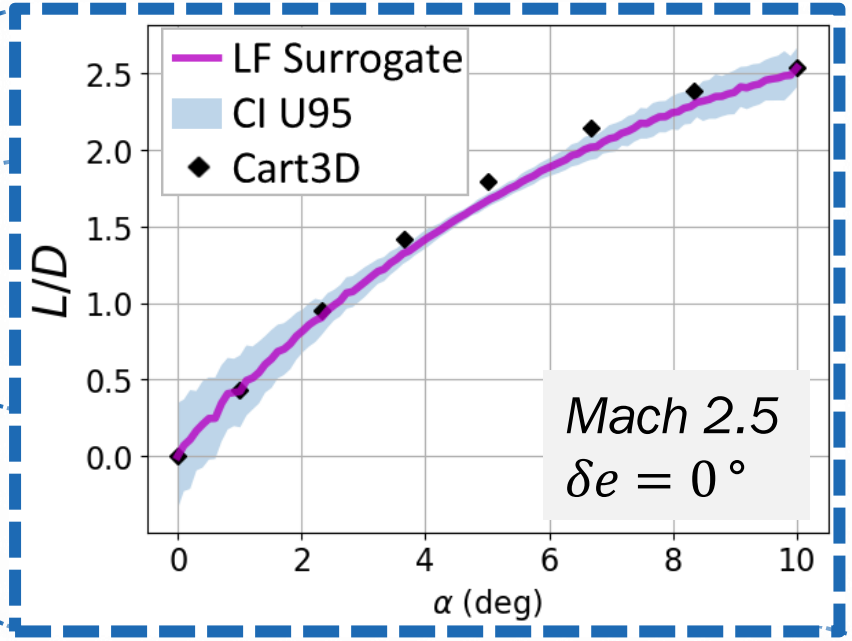


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LF Surrogate Prediction

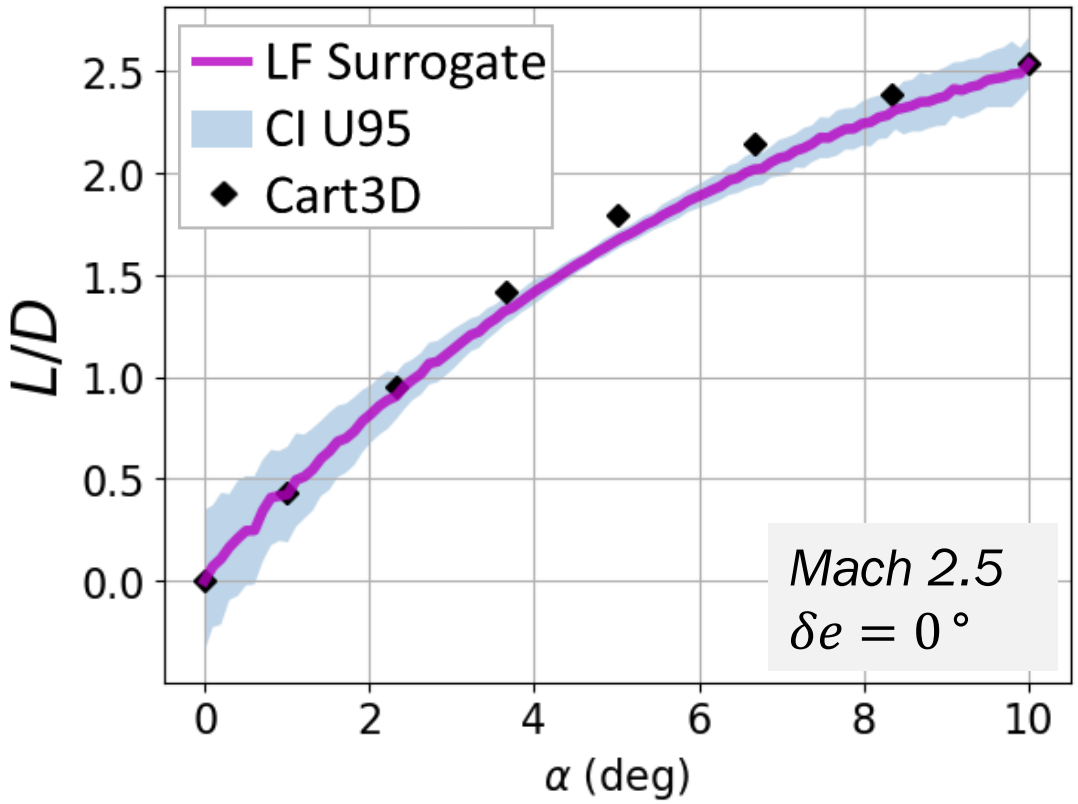
Visualized Across the Multi-Dimensional Parameter Space





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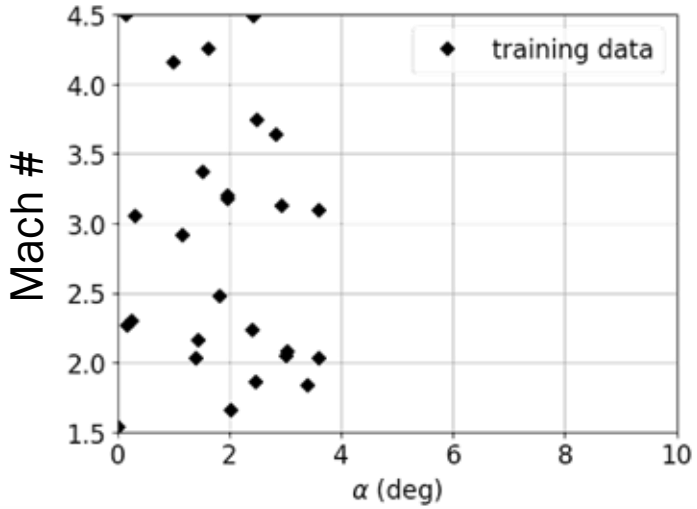
Low-Fidelity Surrogate Achieves Accurate Prediction Against Cart3D Blind Validation Data, and Small Uncertainties



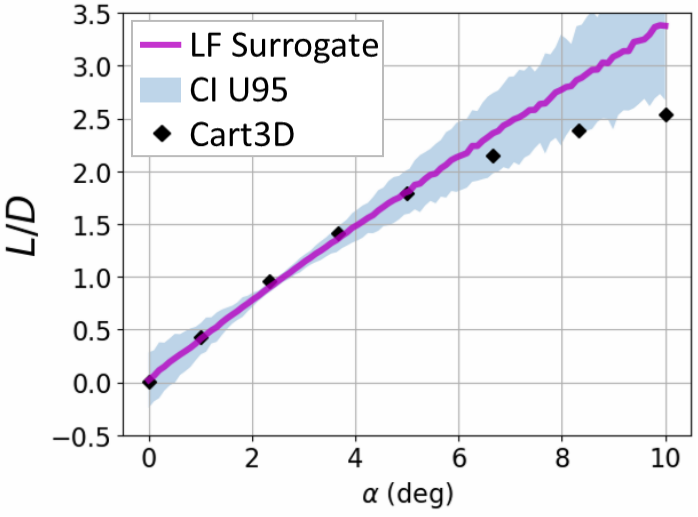
- The LF Surrogate result is smoothed by averaging results with MC dropout
- The upper 95% confidence interval (CI U95)
  1. is determined using MC dropout method
  2. analysis indicates a 95% probability that the true output falls within this range
- Plotted Cart3D results are blind validation data
- CI U95 qualitatively appears overconfident near $\alpha = 5°$
- Clearer assessment of UQ technique is shown on next slide

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Illustration of Effective UQ and Active Learning

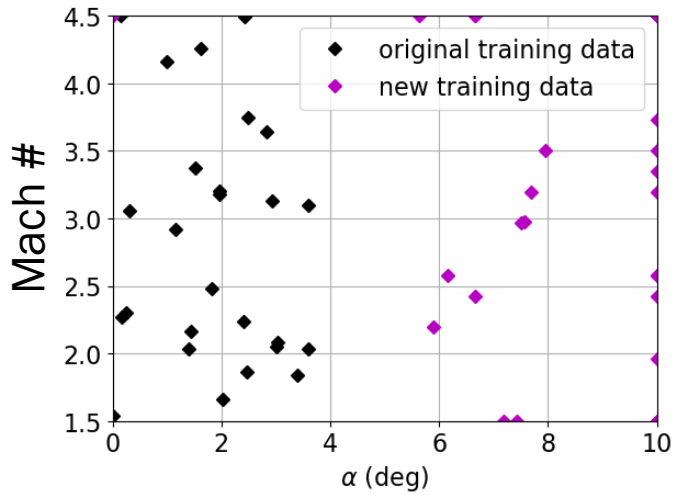


1. Training data restricted to 0°–4°

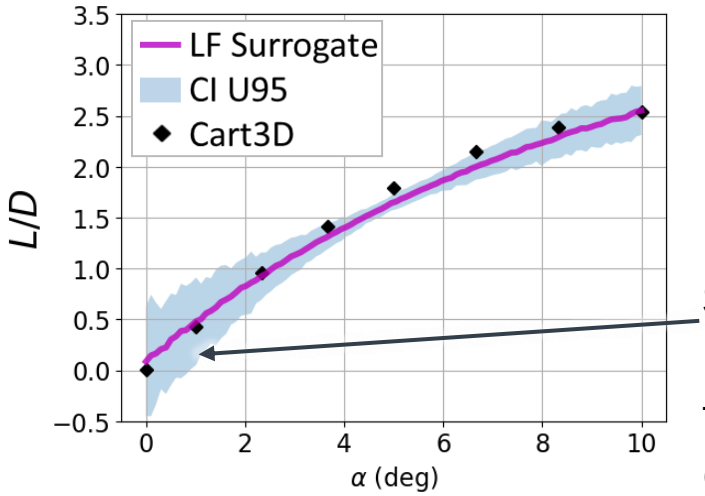


2. Restricted surrogate model performs poorly away from training data

3. CI U95 high away from training data



4. Active learning used to automate selection of new training data

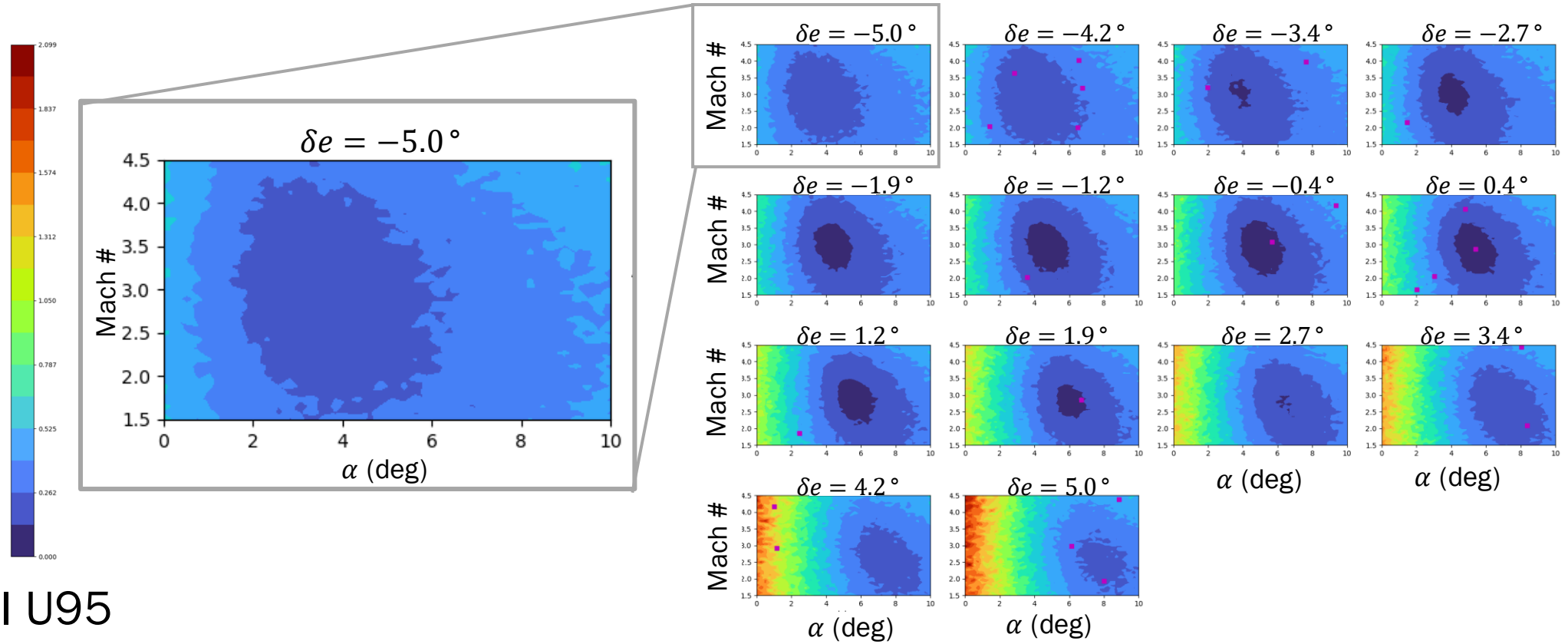


5. Surrogate model performance improves and CI U95 decreases

Slight increase in CI U95 away from new training data may be due to limited network size

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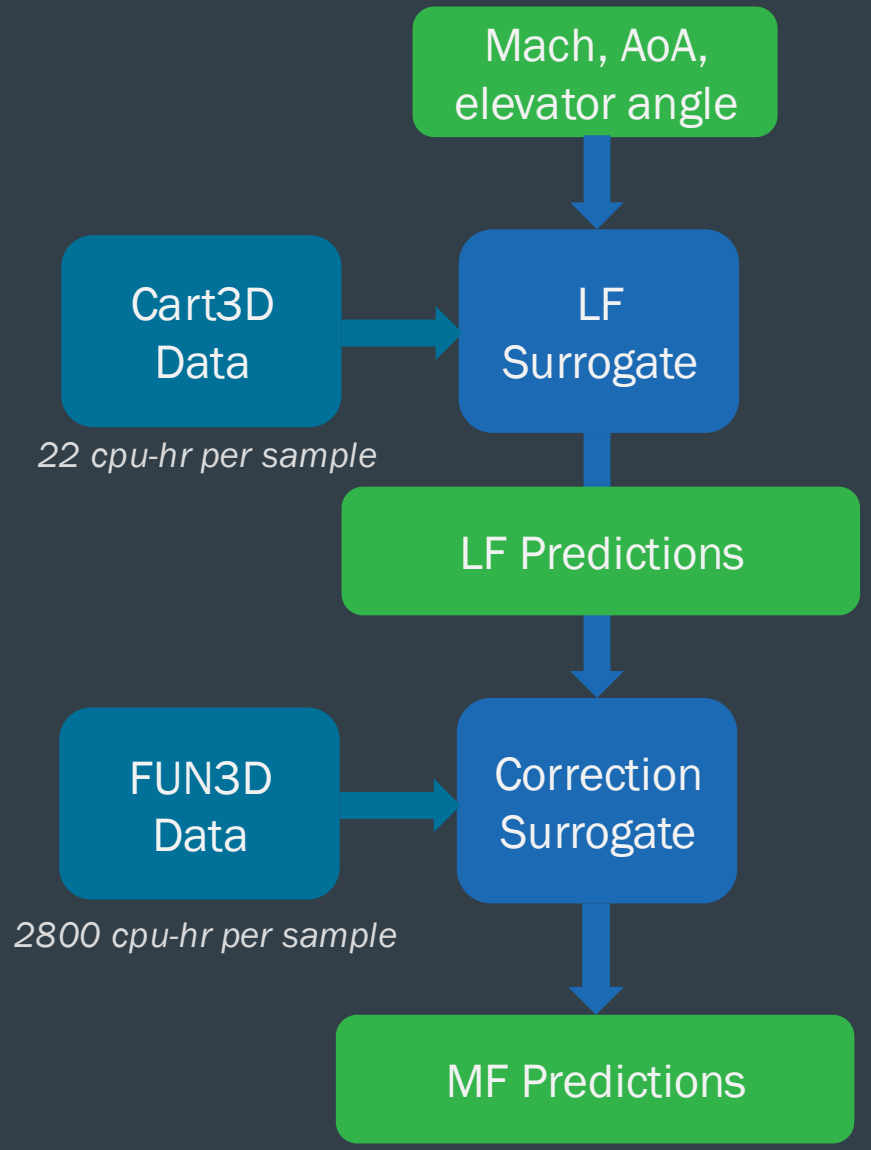
Low Fidelity Network Uncertainty Can Be Quantified Across the Multi-Dimensional Mission Parameter Space



CI U95

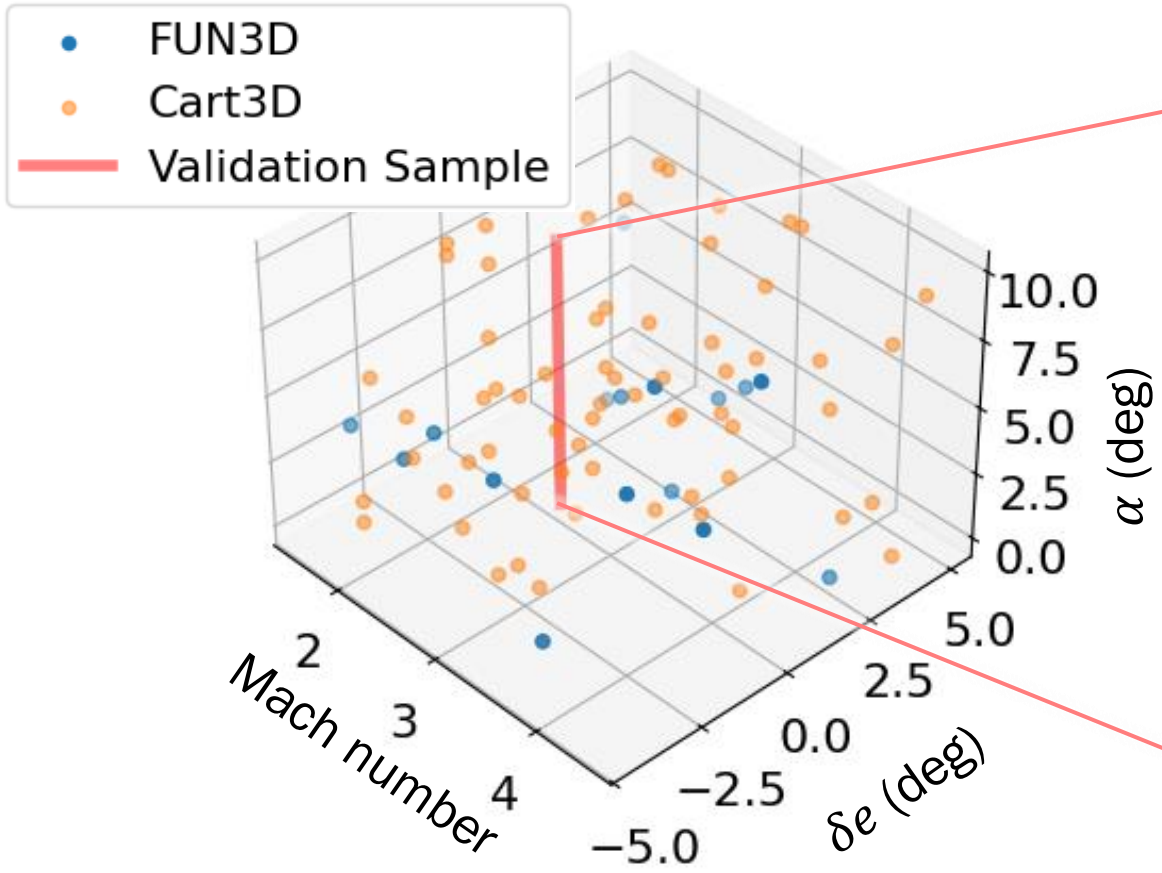
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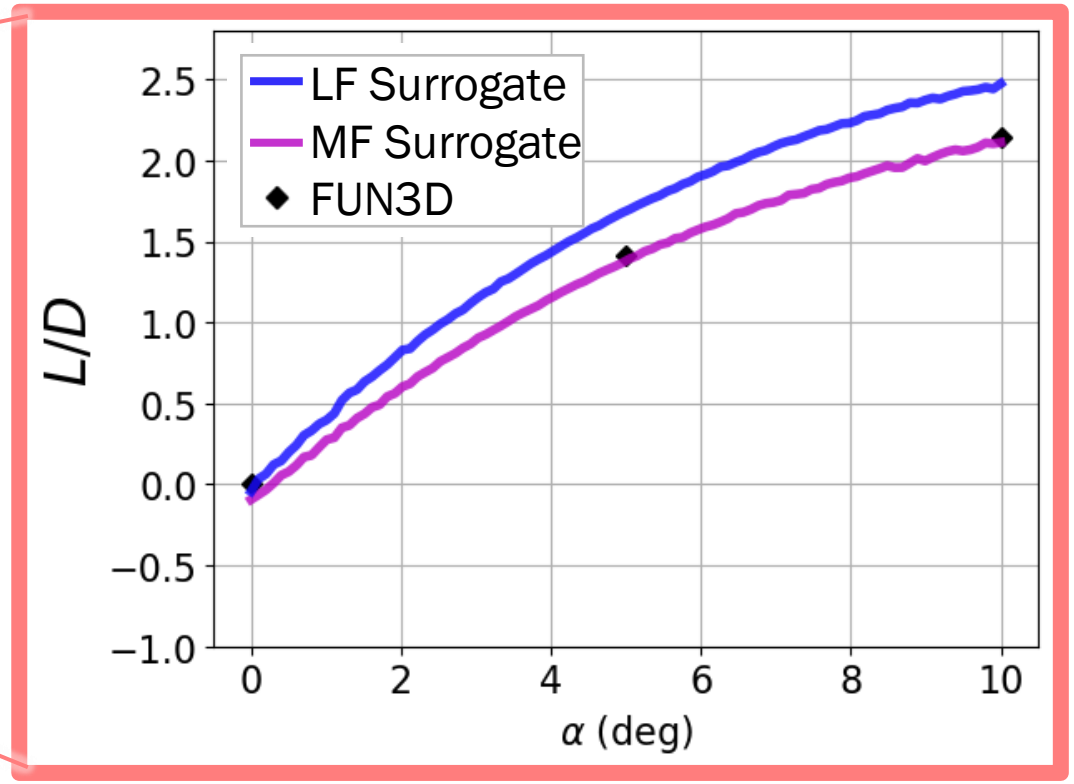
MF Surrogate Modeling Results



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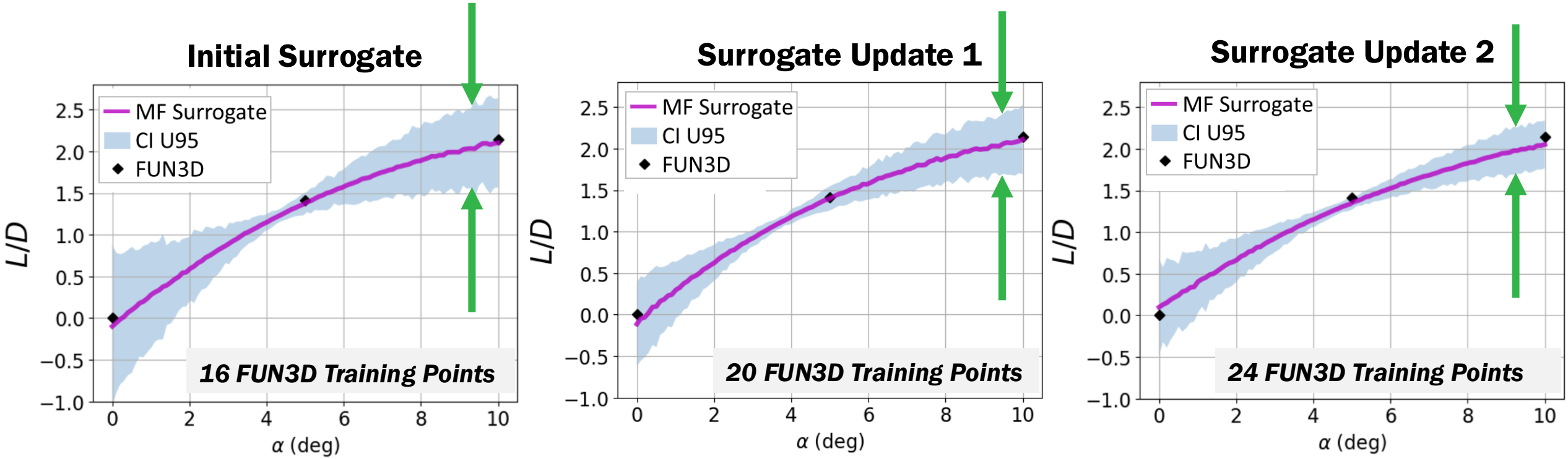
Multifidelity Surrogate Model Approaches FUN3D Accuracy





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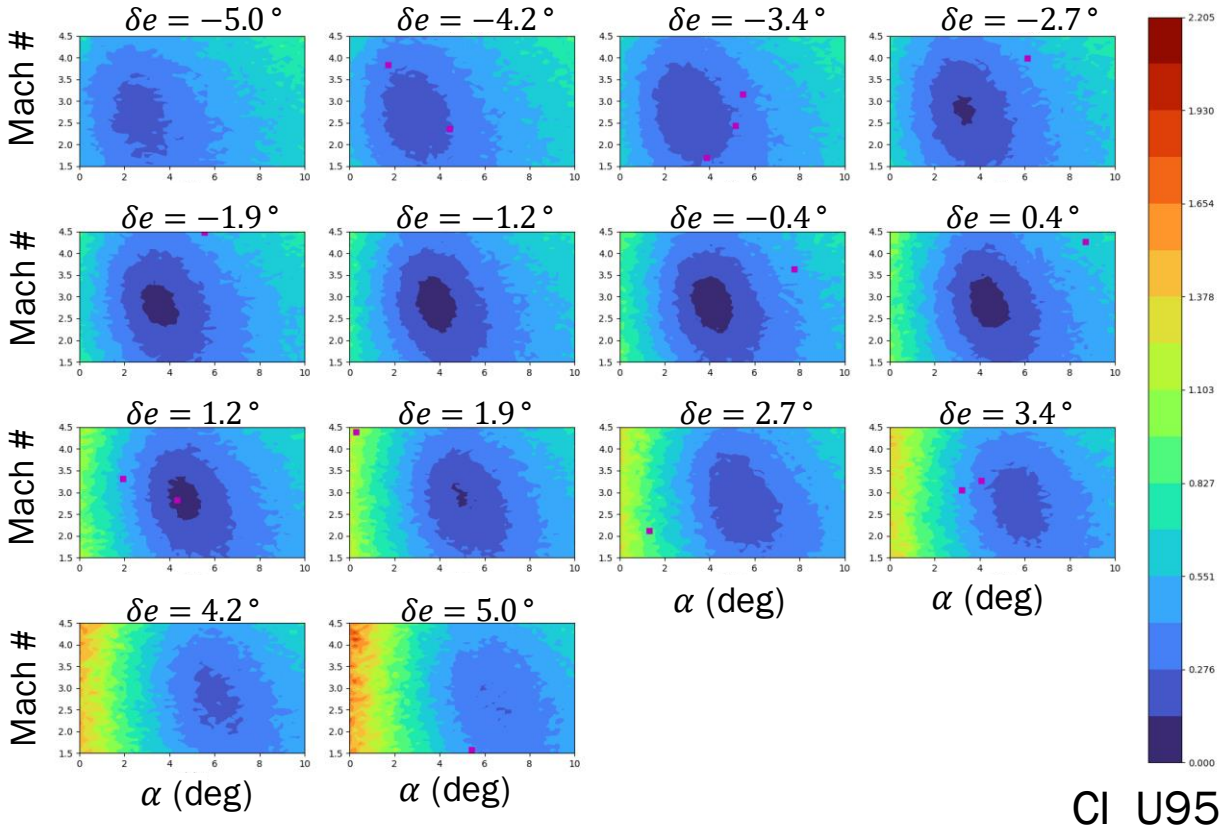
Multifidelity Surrogate Uncertainties Improve with Automated Resampling



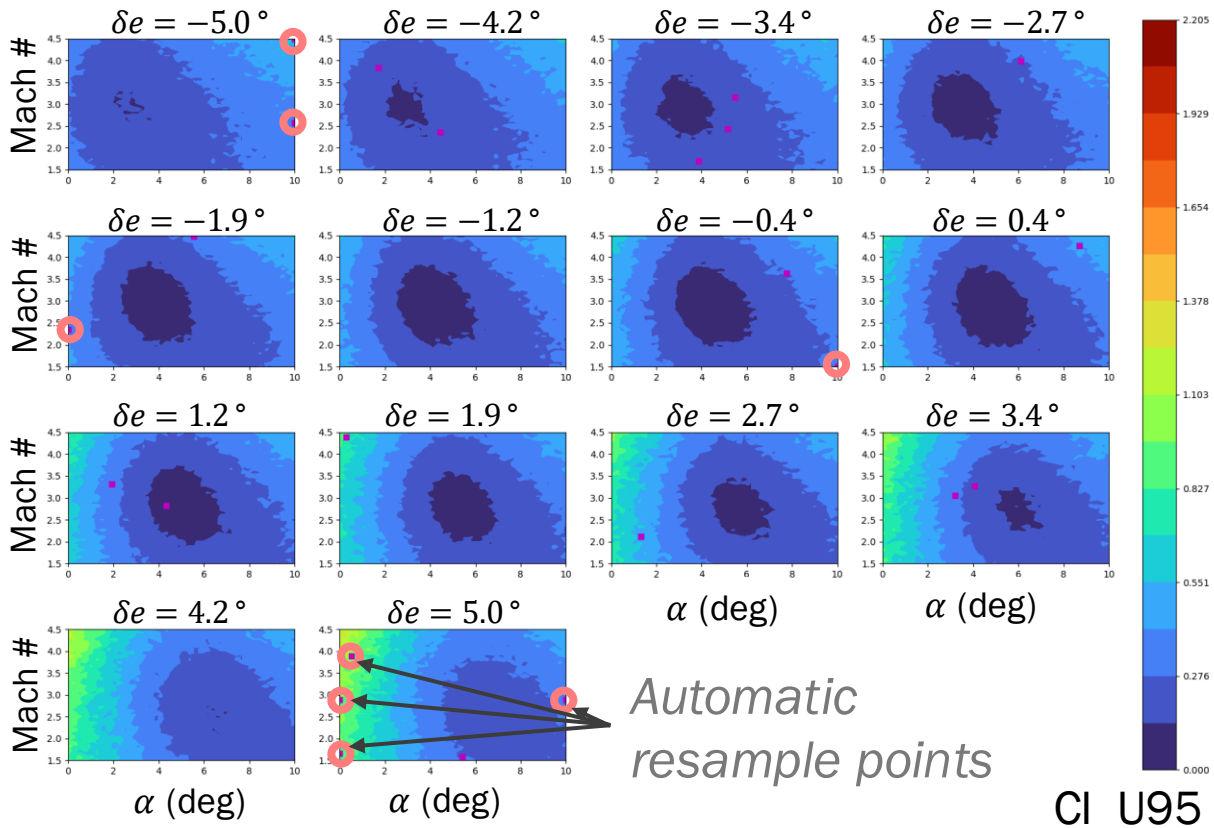
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MF Surrogate Achieves Reasonable Uncertainties in Full Parameter Space

Initial MF Surrogate



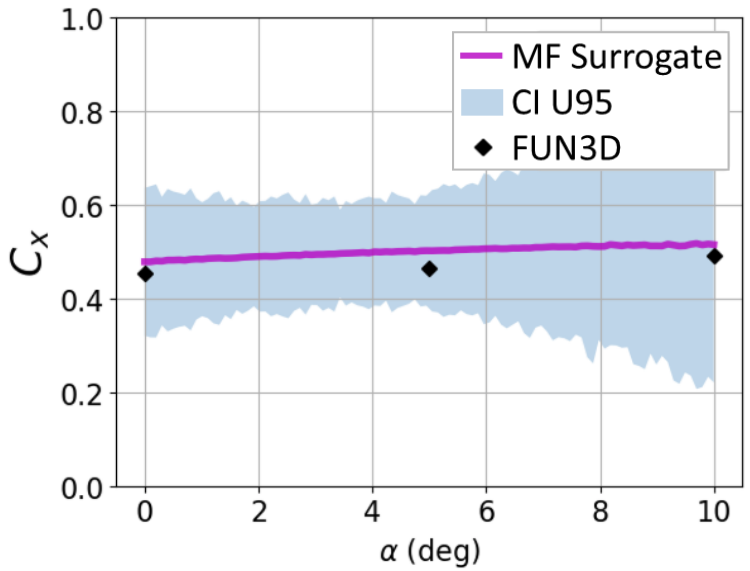
Final MF Surrogate

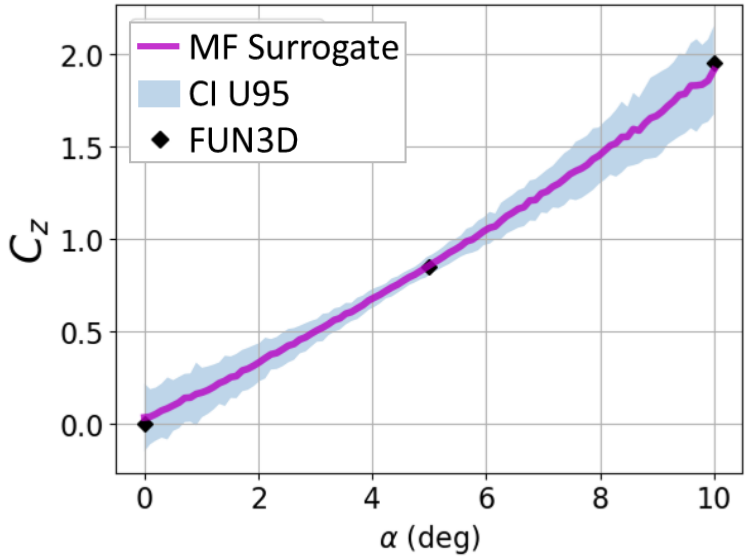


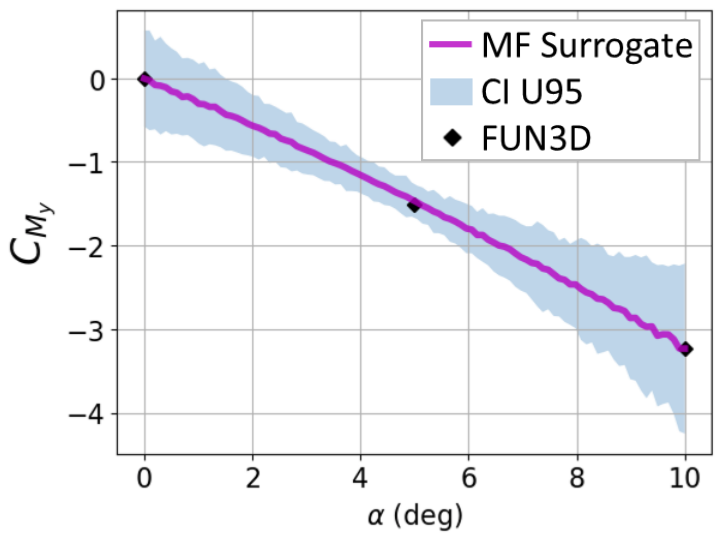
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Other Surrogate Outputs Available for Flight-Dynamics Analysis

Results from Final MF Surrogate



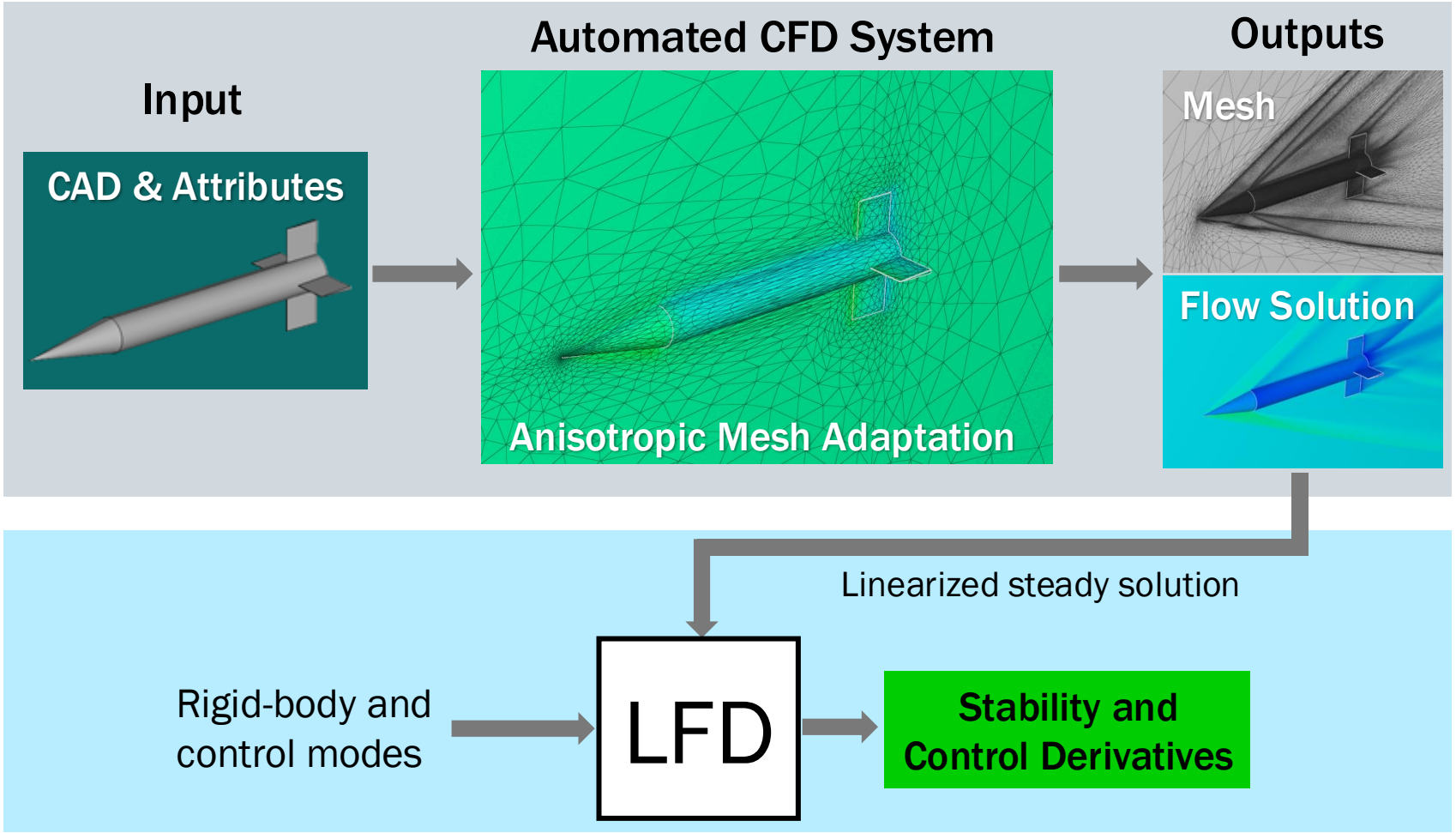




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Stability and Control Derivatives From Adapted Meshes

Finite difference methods perform especially poorly on adapted meshes – alternative method developed



Ricciardi, A.P., J. Trout, E. Blades, and D. Luke. "Direct Computation of Stability and Control Derivatives with Respect to Static, Dynamic, and Unsteady Variables." AIAA SciTech, January 2026.

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- **Main Topic: Automating Aerodynamic Databases for Flight Dynamics**
  1. Executive Summary
  2. Methods
     a) Automated Process Description
     b) Demonstration Case
     c) Automated CFD Methods and Representative Results
     d) Multifidelity Surrogate Modeling and Automatic Sample Selection
  3. Results
     a) LF Surrogate Model
     b) MF Surrogate Model
  4. Conclusions
- **Supplement Topic: Computing Stability and Control Derivatives with Adapted Meshes**
  1. Using generalized aerodynamic force method
  2. Benefits: include damping derivatives in surrogate, gradient-enhanced surrogates

Interim Conclusions on Main Topic

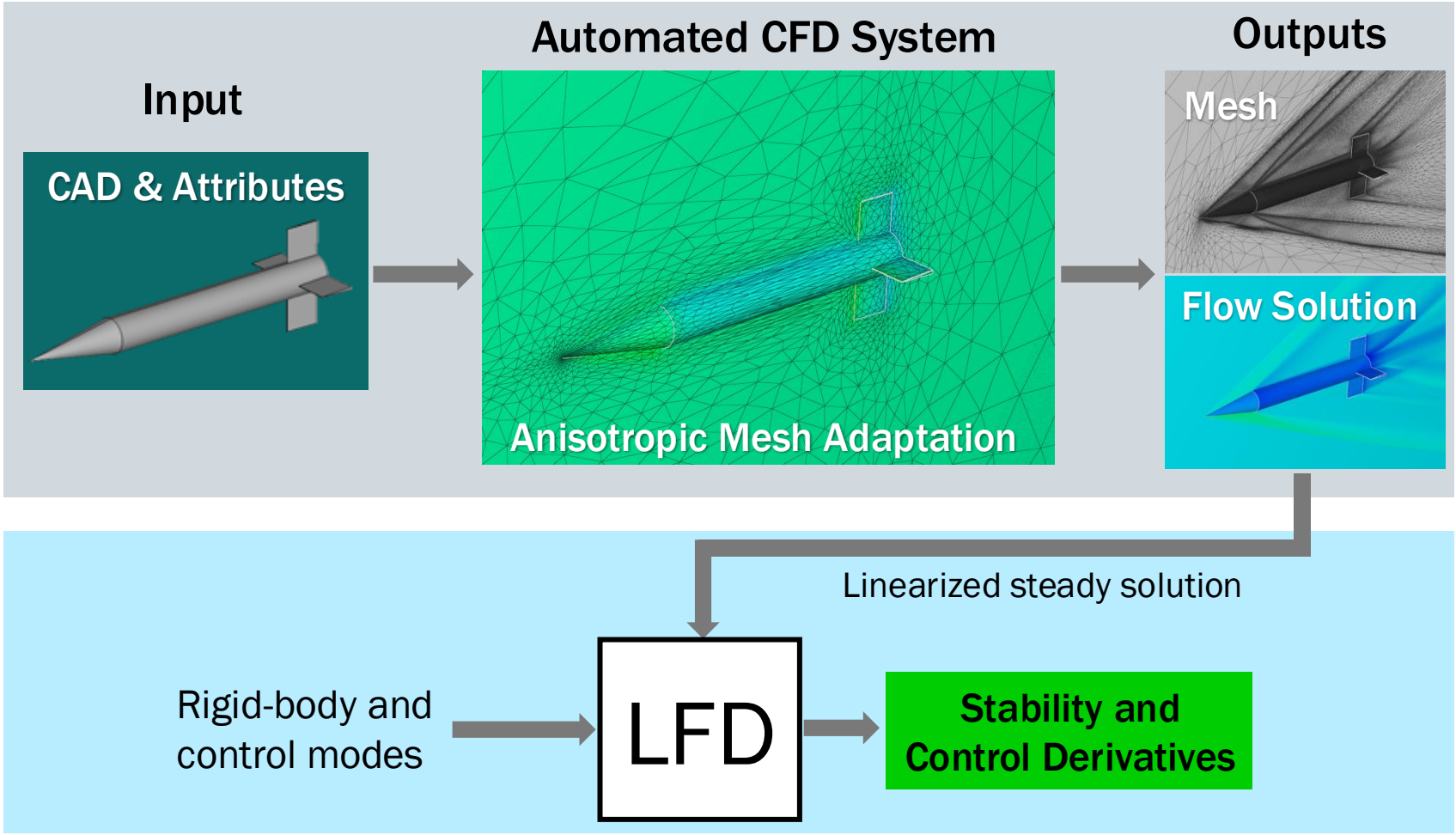
- An autonomous process was developed to create surrogate aerodynamic models for flight-dynamics analysis.
- Provided only with the ANF vehicle geometry and operating envelope, the process
  1. automatically selected multifidelity analysis conditions for inviscid and viscous aerodynamic analysis,
  2. automatically created meshes from the vehicle geometry, and
  3. automatically ensured solution accuracy using state-of-the-art mesh adaptation methods.
- The resulting surrogate model is
  1. suitable for flight-dynamics analysis, and
  2. was generated with less human labor and lower computational cost than would be achievable using traditional methods.
- Future Opportunities:
  1. Establish CI U95 or other thresholds for model convergence – may require error propagation
  2. Apply methods to larger parameter space with greater output variation (e.g., transonic, high α)
  3. Enhance surrogate models using S&C derivatives

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Stability and Control Derivatives From Adapted Meshes

Finite difference methods perform especially poorly on adapted meshes – alternative method developed



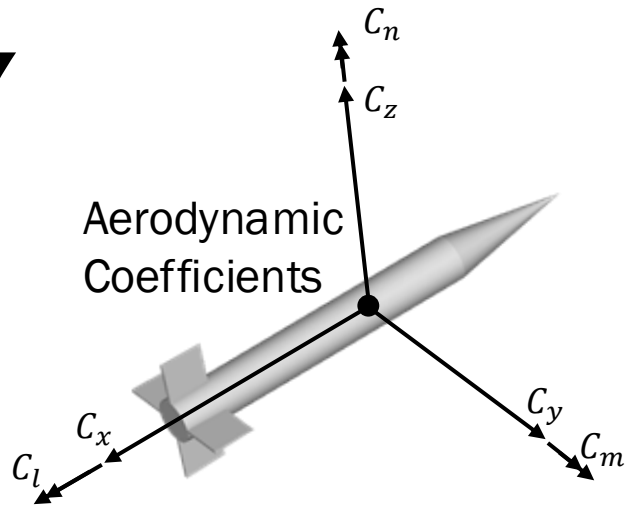
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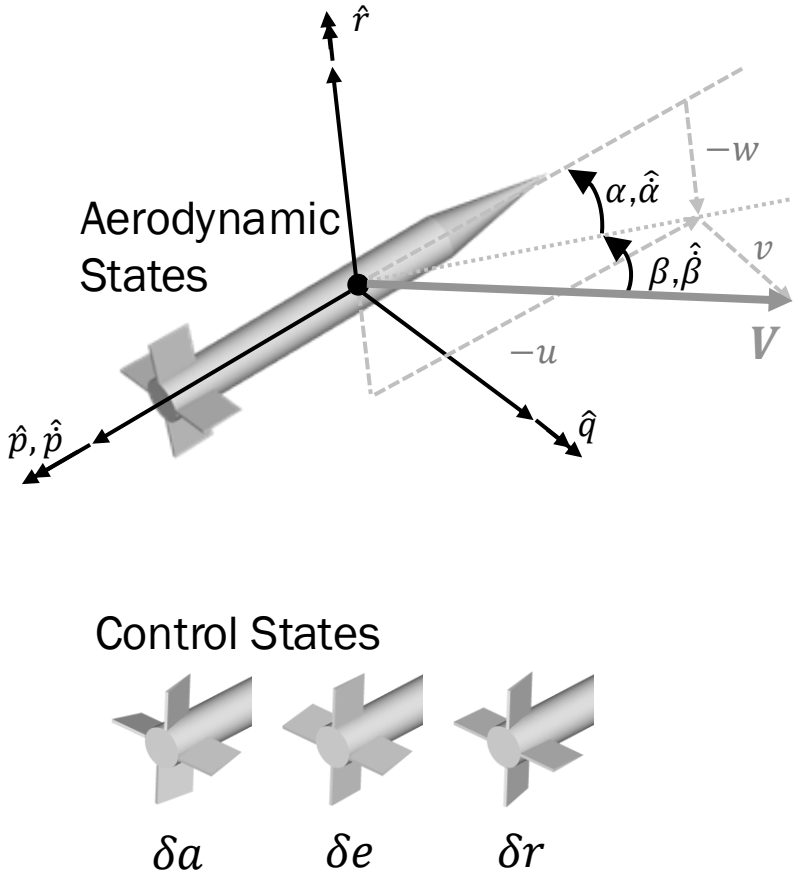
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Stability and Control (S&C) Derivatives

- *Compute cost of GAF method is an order-of-magnitude less than adapting + converging the nonlinear steady state solution*
- *The S&C derivatives can be used to train gradient-enhanced surrogate models*
- *GAF method makes damping derivative calculations easier and supports unsteady derivatives*

$$\partial\left(\quad\right)/\partial\left(\quad\right)$$

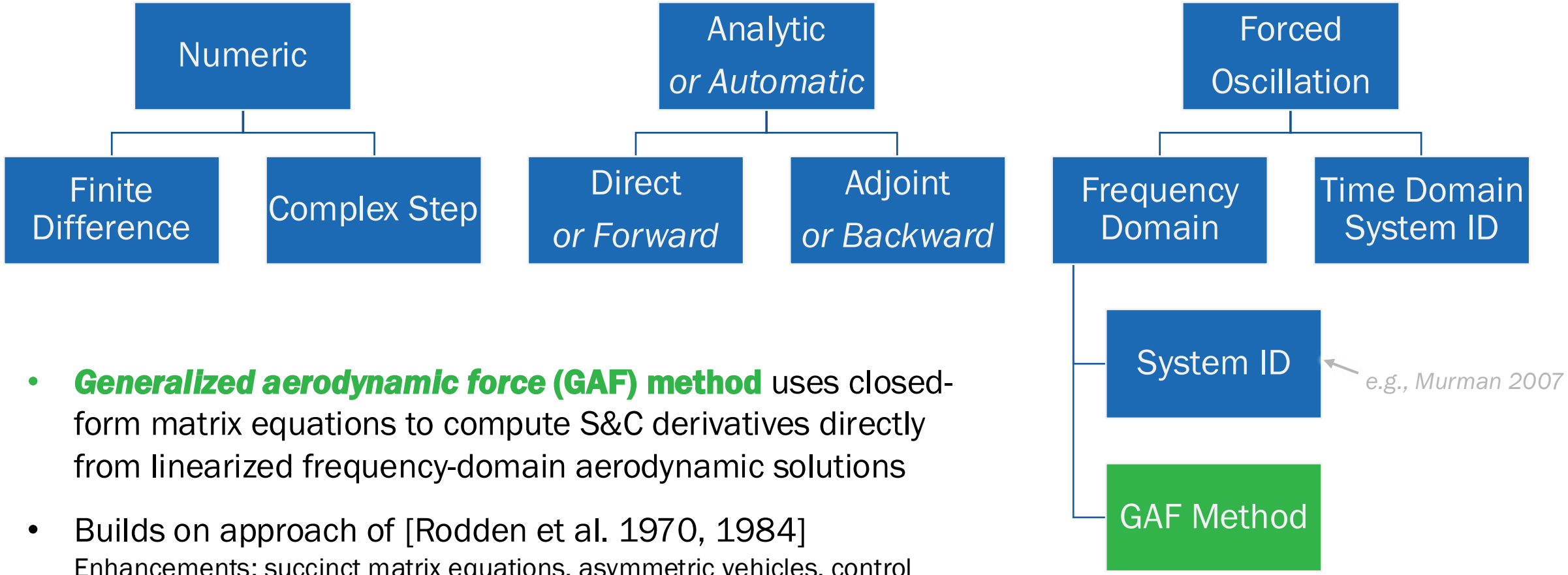




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Taxonomy of S&C Derivative Computation Methods



- ***Generalized aerodynamic force* (GAF) method** uses closed-form matrix equations to compute S&C derivatives directly from linearized frequency-domain aerodynamic solutions
- Builds on approach of [Rodden et al. 1970, 1984]
  Enhancements: succinct matrix equations, asymmetric vehicles, control derivatives, higher-fidelity model demonstration

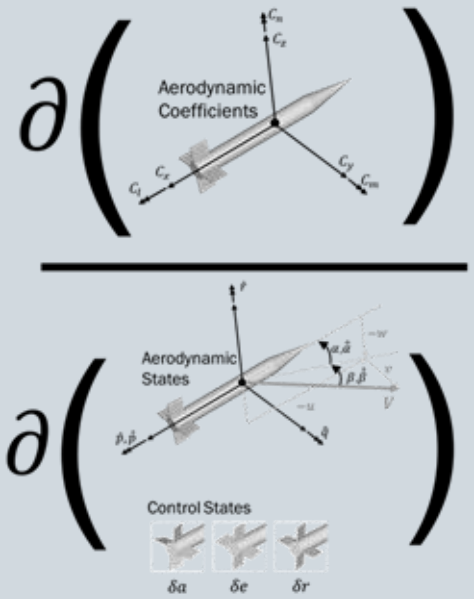
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GAF Method Makes Valuable Information Accessible

Valuable Information

S&C derivatives

$$\frac{\partial(\text{Aerodynamic Coefficients})}{\partial(\text{Aerodynamic States}, \text{Control States})} = \boldsymbol{C_{x_a}} \quad \boldsymbol{C_{x\delta}}$$



$$\boldsymbol{C_{x_a}} = \begin{bmatrix} C_{x_\alpha} & C_{x_\beta} & C_{x_{\hat{p}}} & C_{x_{\hat{q}}} & C_{x_{\hat{r}}} & C_{x_{\hat{\dot{\alpha}}}} & C_{x_{\hat{\dot{\beta}}}} & C_{x_{\hat{\dot{p}}}} \\ C_{y_\alpha} & C_{y_\beta} & C_{y_{\hat{p}}} & C_{y_{\hat{q}}} & C_{y_{\hat{r}}} & C_{y_{\hat{\dot{\alpha}}}} & C_{y_{\hat{\dot{\beta}}}} & C_{y_{\hat{\dot{p}}}} \\ C_{z_\alpha} & C_{z_\beta} & C_{z_{\hat{p}}} & C_{z_{\hat{q}}} & C_{z_{\hat{r}}} & C_{z_{\hat{\dot{\alpha}}}} & C_{z_{\hat{\dot{\beta}}}} & C_{z_{\hat{\dot{p}}}} \\ C_{l_\alpha} & C_{l_\beta} & C_{l_{\hat{p}}} & C_{l_{\hat{q}}} & C_{l_{\hat{r}}} & C_{l_{\hat{\dot{\alpha}}}} & C_{l_{\hat{\dot{\beta}}}} & C_{l_{\hat{\dot{p}}}} \\ C_{m_\alpha} & C_{m_\beta} & C_{m_{\hat{p}}} & C_{m_{\hat{q}}} & C_{m_{\hat{r}}} & C_{m_{\hat{\dot{\alpha}}}} & C_{m_{\hat{\dot{\beta}}}} & C_{m_{\hat{\dot{p}}}} \\ C_{n_\alpha} & C_{n_\beta} & C_{n_{\hat{p}}} & C_{n_{\hat{q}}} & C_{n_{\hat{r}}} & C_{n_{\hat{\dot{\alpha}}}} & C_{n_{\hat{\dot{\beta}}}} & C_{n_{\hat{\dot{p}}}} \end{bmatrix}$$

$$\boldsymbol{C_{x\delta}} = \begin{bmatrix} C_{x_{\delta 1}} & C_{x_{\delta 2}} & \dots & C_{x_{\delta n}} & C_{x_{\hat{\dot{\delta}}1}} & C_{x_{\hat{\dot{\delta}}2}} & \dots & C_{x_{\hat{\dot{\delta}}n}} \\ C_{y_{\delta 1}} & C_{y_{\delta 2}} & \dots & C_{y_{\delta n}} & C_{y_{\hat{\dot{\delta}}1}} & C_{y_{\hat{\dot{\delta}}2}} & \dots & C_{y_{\hat{\dot{\delta}}n}} \\ C_{z_{\delta 1}} & C_{z_{\delta 2}} & \dots & C_{z_{\delta n}} & C_{z_{\hat{\dot{\delta}}1}} & C_{z_{\hat{\dot{\delta}}2}} & \dots & C_{z_{\hat{\dot{\delta}}n}} \\ C_{l_{\delta 1}} & C_{l_{\delta 2}} & \dots & C_{l_{\delta n}} & C_{l_{\hat{\dot{\delta}}1}} & C_{l_{\hat{\dot{\delta}}2}} & \dots & C_{l_{\hat{\dot{\delta}}n}} \\ C_{m_{\delta 1}} & C_{m_{\delta 2}} & \dots & C_{m_{\delta n}} & C_{m_{\hat{\dot{\delta}}1}} & C_{m_{\hat{\dot{\delta}}2}} & \dots & C_{m_{\hat{\dot{\delta}}n}} \\ C_{n_{\delta 1}} & C_{n_{\delta 2}} & \dots & C_{n_{\delta n}} & C_{n_{\hat{\dot{\delta}}1}} & C_{n_{\hat{\dot{\delta}}2}} & \dots & C_{n_{\hat{\dot{\delta}}n}} \end{bmatrix}$$

Accessible Information

$$= \boldsymbol{S_c^{-1}} \left(\boldsymbol{Q_{xx}^{re} T_{xa}^{a}} + \boldsymbol{Q_{xx}^{im} T_{xa}^{b}} \right)$$

$$= \boldsymbol{S_c^{-1}} \left[\boldsymbol{Q_{x\delta}^{re}} \quad \boldsymbol{Q_{x\delta}^{im} T_{\delta\delta}} \right]$$

- $\boldsymbol{Q_{xx}}$ and $\boldsymbol{Q_{x\delta}}$ can be automatically computed using frequency-domain CFD solvers
- $\boldsymbol{S_c}$, $\boldsymbol{T_{xa}^{a}}$, $\boldsymbol{T_{xa}^{b}}$, and $\boldsymbol{T_{\delta\delta}}$ are derived in this work and are inexpensive to assemble

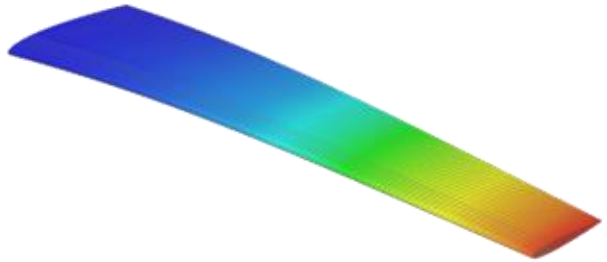
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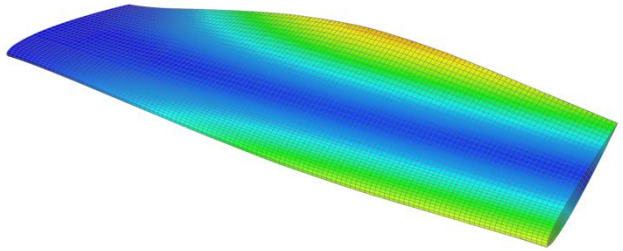
CFD Solvers Support $\boldsymbol{Q}$ Matrix Computation for Aeroelastic Analysis

Example mode shape vectors

$\boldsymbol{\phi}_{\mathrm{k1}}$



$\boldsymbol{\phi}_{\mathrm{k2}}$



Matrix of mode shape vectors

$$\boldsymbol{\Phi_{kh}} = [\boldsymbol{\phi_{k1}}, \boldsymbol{\phi_{k2}}]$$

Coordinate transformation between physical DOF and modal DOF

$$\boldsymbol{u_k} = \boldsymbol{\Phi_{kh}} \boldsymbol{u_h}$$

Modal forces in terms of modal displacements

$$\tilde{\boldsymbol{f}}_{\boldsymbol{h}} = \frac{1}{2}\rho V^2 \boldsymbol{Q_{hh}} \tilde{\boldsymbol{u}}_{\boldsymbol{h}}$$

Aerodynamic solution for $\boldsymbol{Q_{hh}}$

$$\boldsymbol{Q_{hh}} = \left(\frac{1}{2}\rho V^2\right)^{-1} \boldsymbol{\Phi_{kh}^T} [\tilde{\boldsymbol{f}}_{\boldsymbol{k1}} \quad \tilde{\boldsymbol{f}}_{\boldsymbol{k2}}]$$

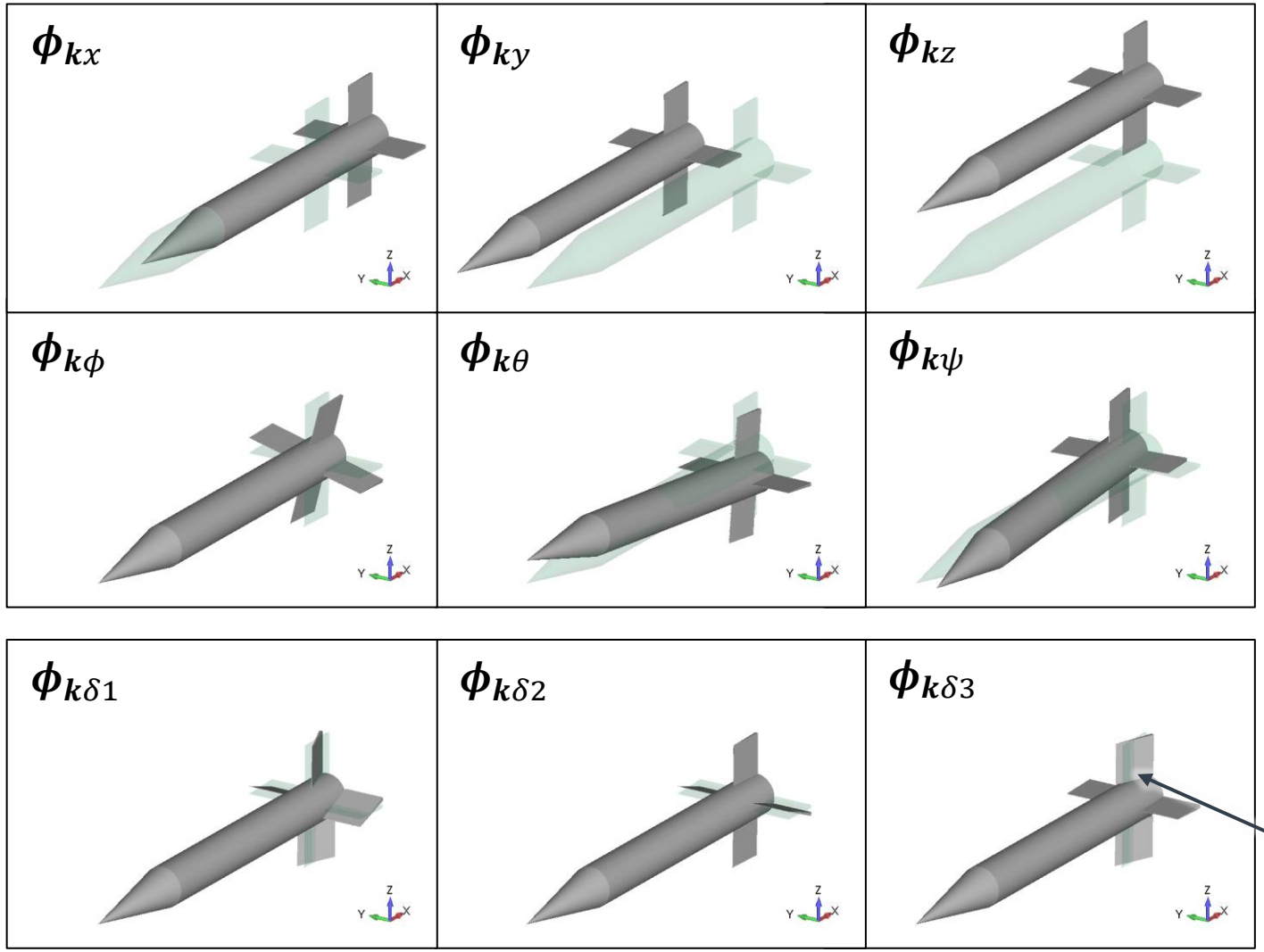
$\tilde{\boldsymbol{f}}_{\boldsymbol{ki}}$ is a complex vector of aerodynamic surface forces corresponding to prescribed motion $\boldsymbol{\phi}_{ki}$

To compute S&C derivatives with GAF method, specify $\boldsymbol{\Phi}$ such that the solver calculates $\boldsymbol{Q_{xx}}$ and $\boldsymbol{Q_{x\delta}}$ for you

Ricciardi, A.P., J. Trout, E. Blades, and D. Luke. "Direct Computation of Stability and Control Derivatives with Respect to Static, Dynamic, and Unsteady Variables." AIAA SciTech, January 2026.

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Forced Oscillation Modes for Computing Q_{xx} and $Q_{x\delta}$



$\rightarrow Q_{xx}$

$\rightarrow Q_{x\delta}$

- $Q_{x\delta}$ is based on quasi-flexible modes
- Extremely high strain near fin root is acceptable with FUND3D LFD

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Derivation of Closed-Form Equations for S&C Derivatives

Known: aerodynamic coefficients in terms of generalized aerodynamic force matrices and prescribed modes

$$\tilde{\boldsymbol{C}}_{\boldsymbol{x}} = \boldsymbol{S}_{\boldsymbol{c}}^{-1}[\boldsymbol{Q}_{\boldsymbol{xx}} \quad \boldsymbol{Q}_{\boldsymbol{x\delta}}] \begin{Bmatrix} \tilde{\boldsymbol{u}}_{\boldsymbol{x}} \\ \tilde{\boldsymbol{u}}_{\boldsymbol{\delta}} \end{Bmatrix}$$

Assumed: form of linearized flight-dynamic model

$$\tilde{\boldsymbol{C}}_{\boldsymbol{x}} \approx \boldsymbol{C}_{\boldsymbol{x}_a} \begin{Bmatrix} \tilde{\alpha} \\ \tilde{\beta} \\ \tilde{\hat{p}} \\ \tilde{\hat{q}} \\ \tilde{\hat{r}} \\ \tilde{\dot{\hat{\alpha}}} \\ \tilde{\dot{\hat{\beta}}} \\ \tilde{\dot{\hat{p}}} \end{Bmatrix} + \boldsymbol{C}_{\boldsymbol{x}_\delta} \begin{Bmatrix} \widetilde{\delta 1} \\ \widetilde{\delta 2} \\ \vdots \\ \widetilde{\delta n} \\ \widetilde{\dot{\delta} 1} \\ \widetilde{\dot{\delta} 2} \\ \vdots \\ \widetilde{\dot{\delta} n} \end{Bmatrix}$$

Solve for: $\boldsymbol{C}_{\boldsymbol{x}_a}$ and $\boldsymbol{C}_{\boldsymbol{x}_\delta}$ in terms of $\boldsymbol{Q}$ matrices – algebraically involved, **see paper for details.**

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GAF Method Equations for S&C Derivatives

$$\boldsymbol{C_{x_a}} = \boldsymbol{S_c^{-1}}\left(\boldsymbol{Q_{xx}^{re}T_{xa}^{a}} + \boldsymbol{Q_{xx}^{im}T_{xa}^{b}}\right)$$

$$\boldsymbol{C_{x_\delta}} = \boldsymbol{S_c^{-1}}\left[\boldsymbol{Q_{x\delta}^{re}} \quad \boldsymbol{Q_{x\delta}^{im}T_{\delta\delta}}\right]$$

$$\boldsymbol{T_{xa}^{a}} = \begin{array}{c} \begin{matrix} \alpha & \beta & \hat{p} & \hat{q} & \hat{r} & \hat{\dot{\alpha}} & \hat{\dot{\beta}} & \hat{\dot{p}} \end{matrix} \\ \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{2b^2}{\bar{c}_n k^2} & 0 & \frac{-2b^2}{\bar{c}_n k^2} & 0 \\ 0 & 0 & 0 & \frac{-2b^2}{\bar{c}_m k^2} & 0 & \frac{2b^2}{\bar{c}_m k^2} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{-2b^2}{\bar{c}_l k^2} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \end{array}$$

$$\boldsymbol{S_c} = S\begin{bmatrix} 1 & & & & & \\ & 1 & & & & \\ & & 1 & & & \\ & & & \bar{c}_l & & \\ & & & & \bar{c}_m & \\ & & & & & \bar{c}_n \end{bmatrix}$$

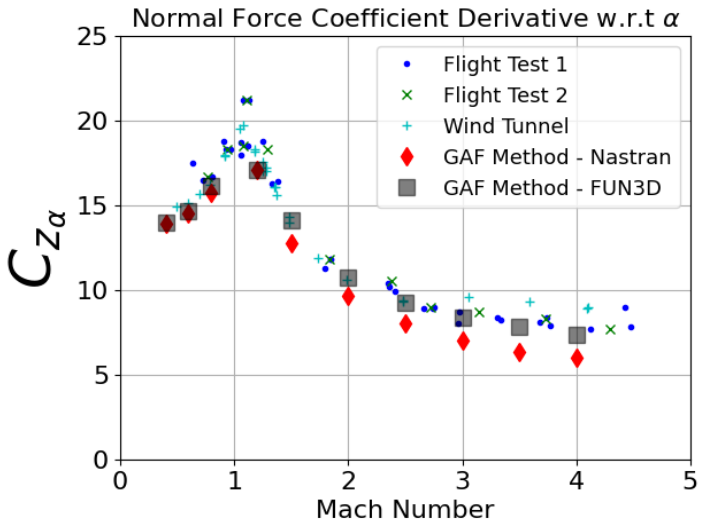
$$\boldsymbol{T_{xa}^{b}} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{b}{k} & 0 & 0 & 0 & 0 & 0 & 0 \\ \frac{-b}{k} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{2b}{\bar{c}_l k} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{2b}{\bar{c}_m k} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{2b}{\bar{c}_n k} & 0 & 0 & 0 \end{bmatrix}$$

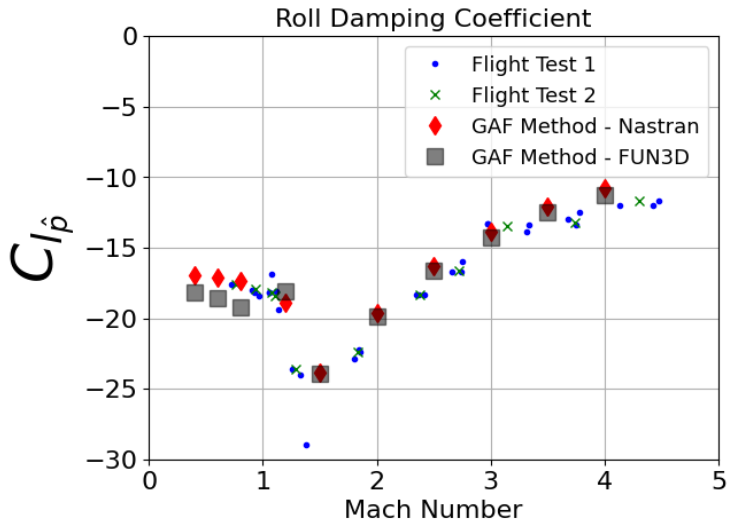
$$\boldsymbol{T_{\delta\delta}} = \begin{bmatrix} \frac{2b}{\bar{c}_j k} & & \\ & \ddots & \\ & & \frac{2b}{\bar{c}_n k} \end{bmatrix}$$

Ricciardi, A.P., J. Trout, E. Blades, and D. Luke. "Direct Computation of Stability and Control Derivatives with Respect to Static, Dynamic, and Unsteady Variables." AIAA SciTech, January 2026.

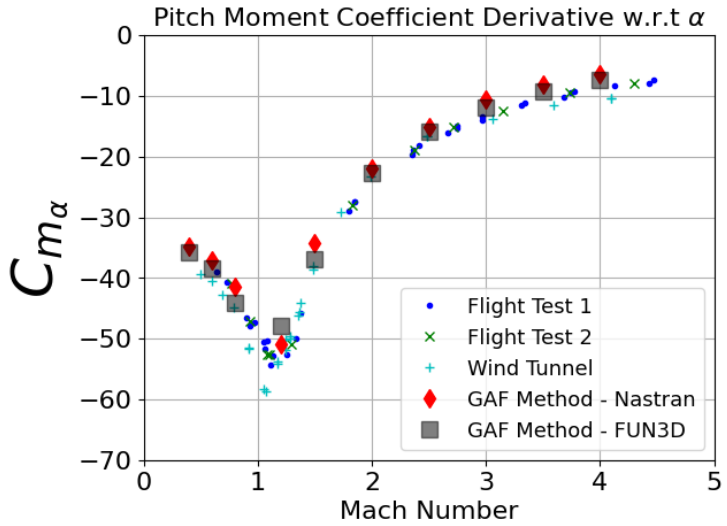
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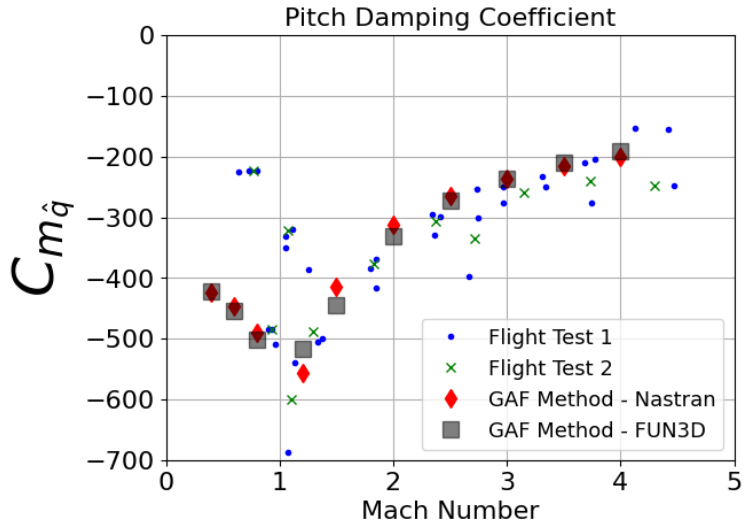
Stability and Control Derivatives are Consistent with Experiment

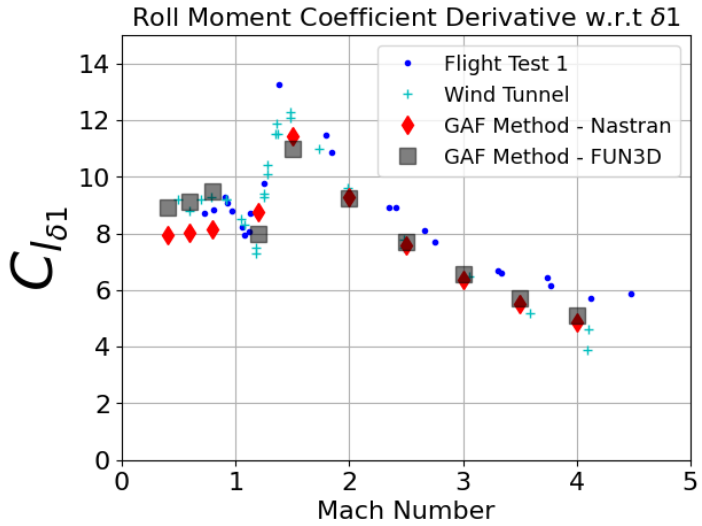












Ricciardi, A.P., J. Trout, E. Blades, and D. Luke. "Direct Computation of Stability and Control Derivatives with Respect to Static, Dynamic, and Unsteady Variables." AIAA SciTech, January 2026.

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Supplement Topic Conclusions

GAF method

- was developed, verified, and validated
- is compatible with adapted meshes and high-fidelity solvers (e.g., FUN3D LFD)
- efficiently and accurately computes S&C derivatives, which may be useful for enhancing surrogate models
- directly provides derivatives w.r.t. damping variables (i.e., p, q, r),
- provides S&C derivatives w.r.t. unsteady variables (i.e., $\dot{\alpha}$, $\dot{\beta}$, $\dot{p}$, and $\dot{\delta}$), which are unobtainable from steady-state analytic methods (e.g., adjoint method)

Ricciardi, A.P., J. Trout, E. Blades, and D. Luke. "Direct Computation of Stability and Control Derivatives with Respect to Static, Dynamic, and Unsteady Variables." AIAA SciTech, January 2026.
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Thank You -- Questions?

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Repeat Conclusions on Main Topic

- An autonomous process was developed to create surrogate aerodynamic models for flight-dynamics analysis.
- Provided only with the ANF vehicle geometry and operating envelope, the process
  1. automatically selected multifidelity analysis conditions for inviscid and viscous aerodynamic analysis,
  2. automatically created meshes from the vehicle geometry, and
  3. automatically ensured solution accuracy using state-of-the-art mesh adaptation methods.
- The resulting surrogate model is
  1. suitable for flight-dynamics analysis, and
  2. was generated with less human labor and lower computational cost than would be achievable using traditional methods.
- Future Opportunities:
  1. Establish CI U95 or other thresholds for model convergence – may require error propagation
  2. Apply methods to larger parameter space with greater output variation (e.g., transonic, high α)
  3. Enhance surrogate models using S&C derivatives

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