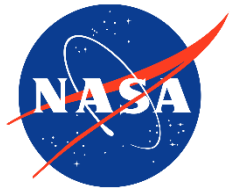

KEVIN T. CROFTON DEPARTMENT OF AEROSPACE AND OCEAN ENGINEERING

Application of Framework for Estimating Performance and Associated Uncertainty for Modified Aircraft Configurations Using NASA's X-57 Maxwell

Casey Denham

Aeronautics System Analysis Branch, Systems Analysis and Concepts Directorate
NASA Langley Research Center

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Outline

- Motivation and Related Research
- Framework for Estimating Performance of Modified Configurations
- X-57 Maxwell
  - Generation of Baseline Models
  - Generation of Tuned Model
  - Uncertainty Estimation
  - Validation of Mod-I Performance
  - Prediction of Mod-II and Mod-III Performance
- Summary and Future Work

Motivation and Related Research

- This project arose out of collaboration with the Virginia Tech Airworthiness Center and NAVAIR
- NAVAIR must perform an airworthiness certification on a growing number of aircraft and configurations
  - This includes flight testing, which has significant time and monetary costs
- Virginia Tech's Nonlinear Systems Lab has previously used non-deterministic simulations to predict aircraft performance and loss of control
- **How can we estimate the performance and uncertainty of modified aircraft without flight testing?**

E-SPARRO UAS. [1]

AeroStar UAS. [2]

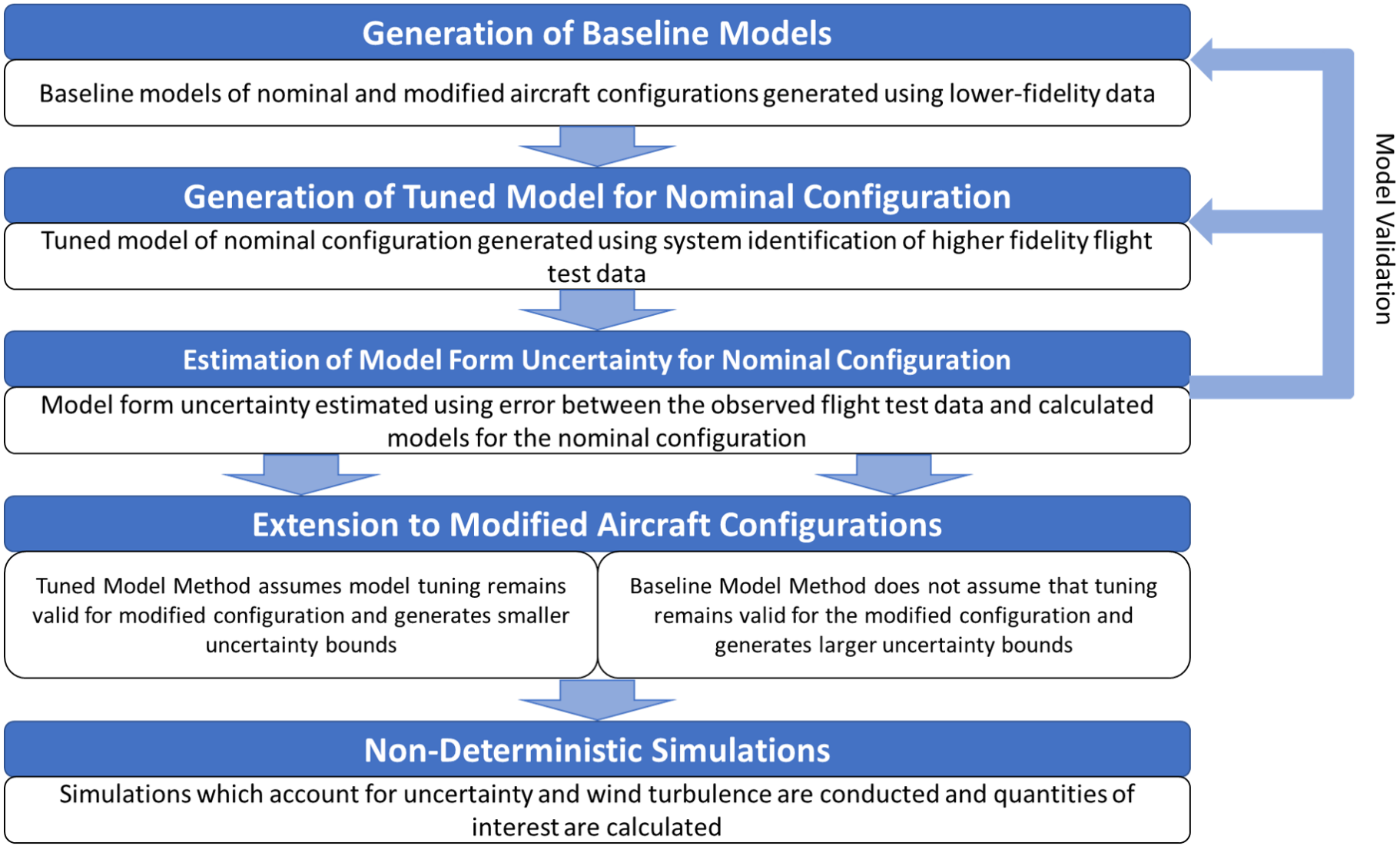
[1] Hale, L. E., et. al., "Nondeterministic Simulation for Probability of Loss of Control Prediction for Unmanned Aircraft Systems", *2015 AIAA AVIATION Forum*, AIAA 2015-2329.
[2] Schafer, T., "HPC Tools Clear the Path for Unmanned Air Vehicles", *DOD HPC Insights*, Spring 2013, pp 5-11.

Framework for Estimating Performance and Uncertainty

- Framework developed to meet the goal of estimating the performance of modified aircraft configurations, including uncertainty
  - Framework includes two methods to account for small and moderate modifications
- Framework designed to be independent of the data sources, model form, or system identification method used
- Framework tested using simulated flight test data of NASA's GTM aircraft

Denham, C. L., Patil, M., Roy, C. J., and Alexandrov, N., "Framework for Estimating Performance and Associated Uncertainty for Modified Aircraft Configurations," Aerospace, Vol. 9, No. 9, Sep 2022, p. 490. doi:10.3390/aerospace9090490.

Generalized Framework



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NASA's X-57 Maxwell

- The X-57 Maxwell is an experimental aircraft that aims to demonstrate the benefits of distributed electric propulsion through a series of incremental modifications to a commercially available aircraft
- Tecnam P2006T serves as a basis for both performance and certification criteria

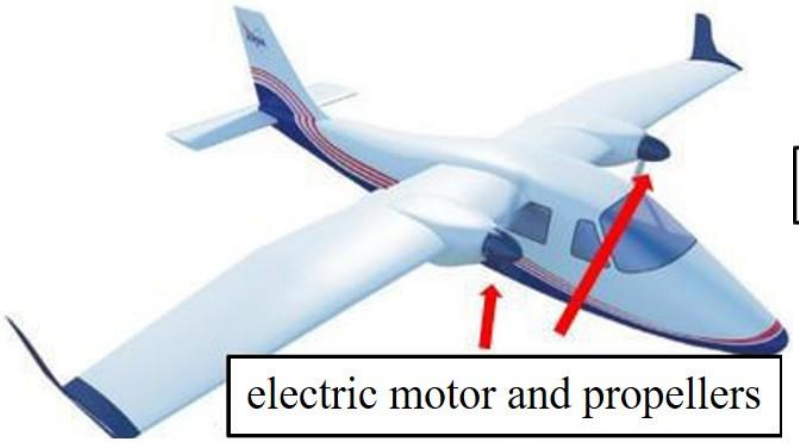
Visualization of X-57 Maxwell in flight. [3]

Visualization of X-57 Maxwell Mod IV.

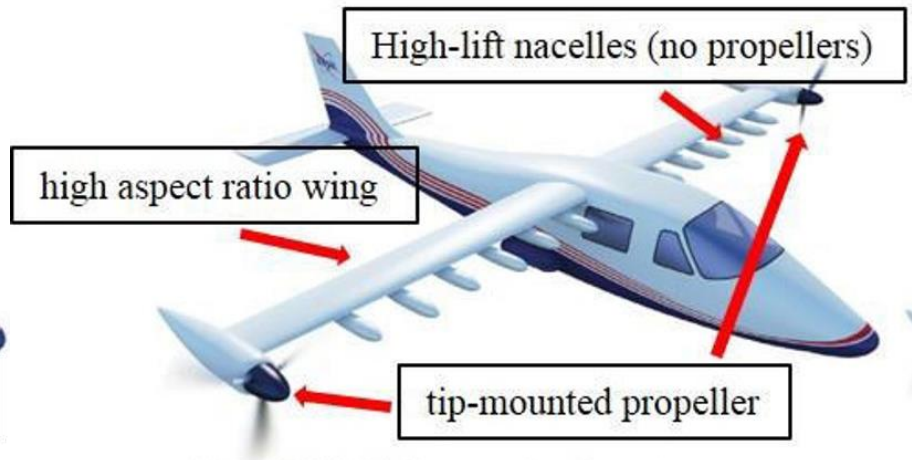
[3] "NASA Releases Concept Images of All-Electric X-57 in Final Configuration", https://www.nasa.gov/centers/armstrong/features/concept-images-of-X-57-final-configuration-released.html [Accessed 06 May 2022].

X-57 Maxwell Configurations

a) Mod-I: Original Tecnam-P2006T



b) Mod-II: Electric motor and propellers



c) Mod-III: High aspect ratio wing, high-lift nacelles (no propellers), tip-mounted propellers

Incremental modifications of the X-57 Maxwell, from the Tecnam P2006T to the complete distributed electric propulsion aircraft. [4]

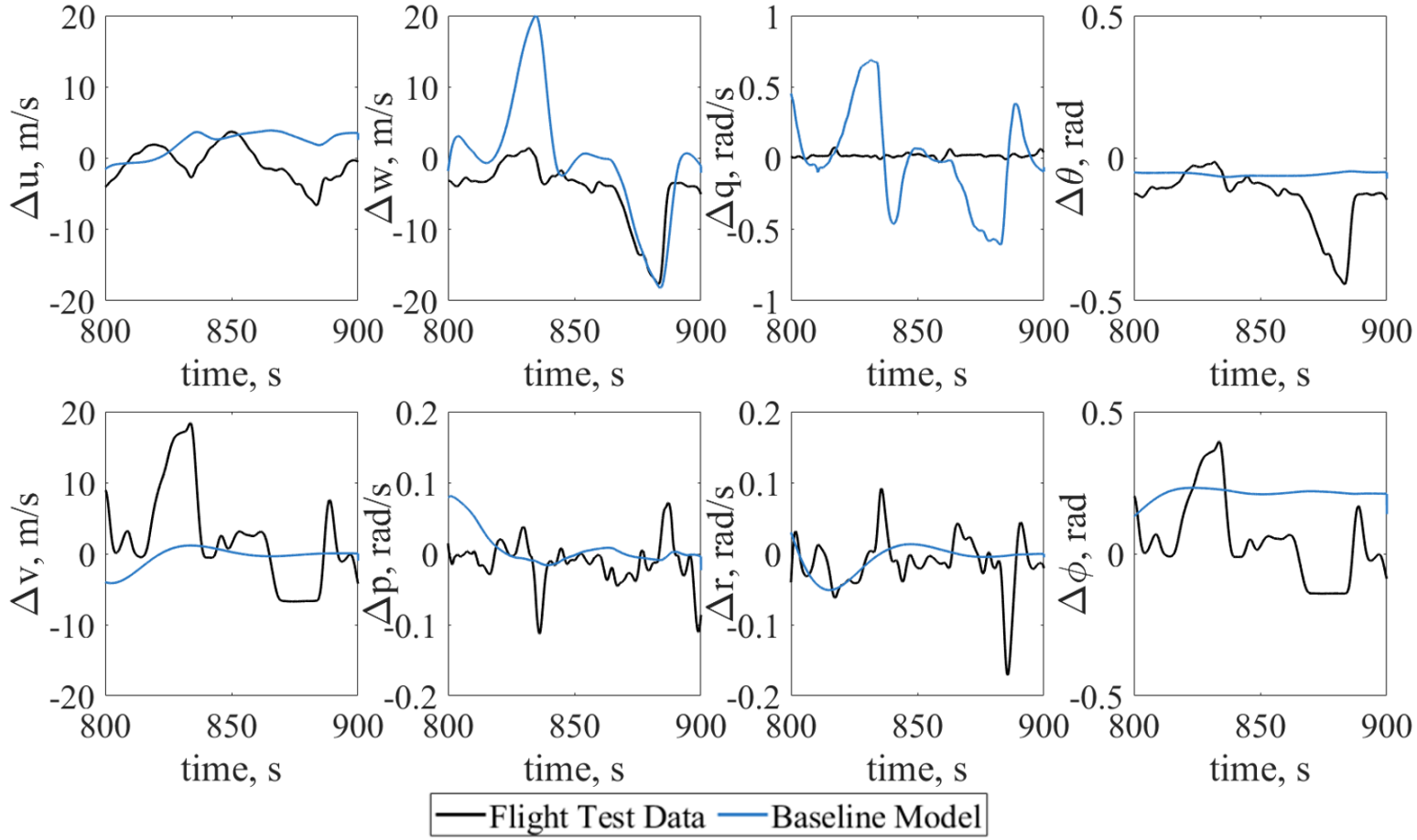
[4] Yoo, S., and Duensing, J., "Computational Analysis of the External Aerodynamics of the Unpowered X-57 Mod-III Aircraft," *AIAA Aviation 2019 Forum*, 2019. doi:10.2514/6.2019-3698

Analysis of X-57 Configuration Performance

- Framework applied to the X-57 using available flight test data for the Tecnam P2006T and simulation models for the modifications based on wind tunnel and CFD analysis
  - Generation of models
  - Uncertainty estimation
  - Validation of results for nominal configuration
- Performance for these modifications is not known – Mod II and Mod III flight tests have not occurred

Generation of Baseline Model

Baseline models for the nominal and modified configurations generated from linear models based on CFD and wind tunnel data



Comparison of flight test data and the baseline model generated from CFD and wind tunnel data

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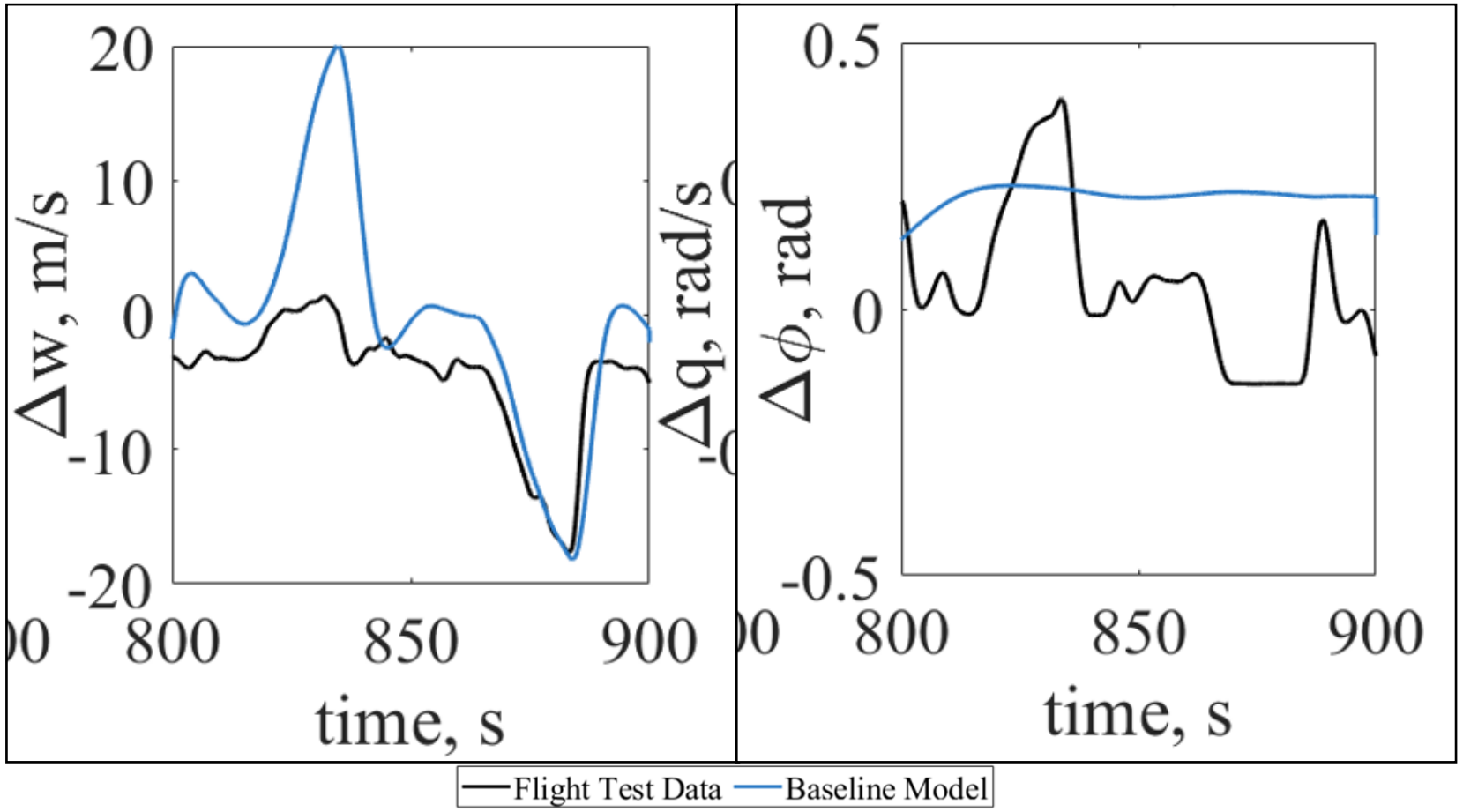
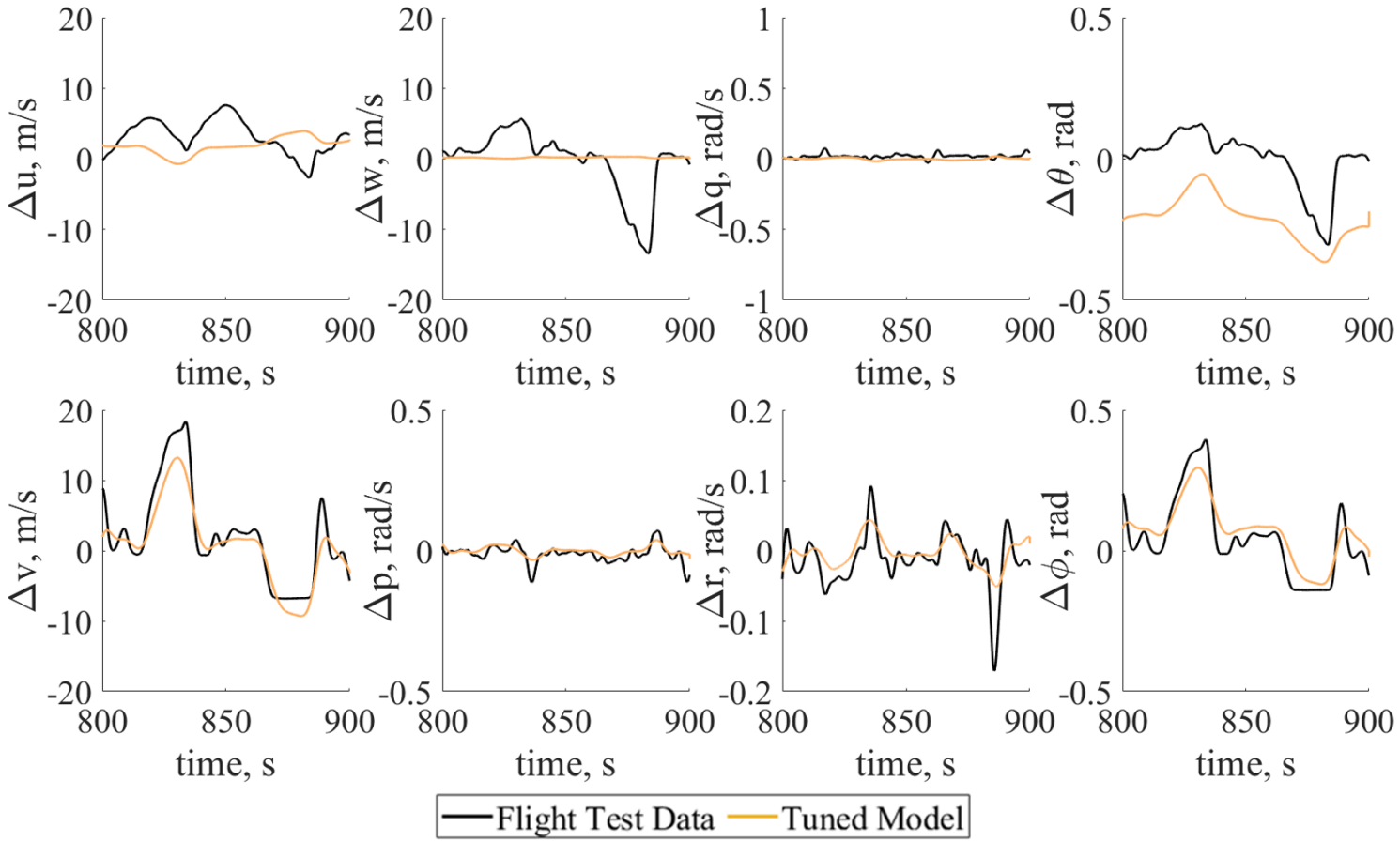


Comparison of flight test data and the baseline model generated from CFD and wind tunnel data

Generation of Tuned Model

Tuned model of the nominal, Mod-I, configuration created using system identification of flight test data of a Tecnam P2006T



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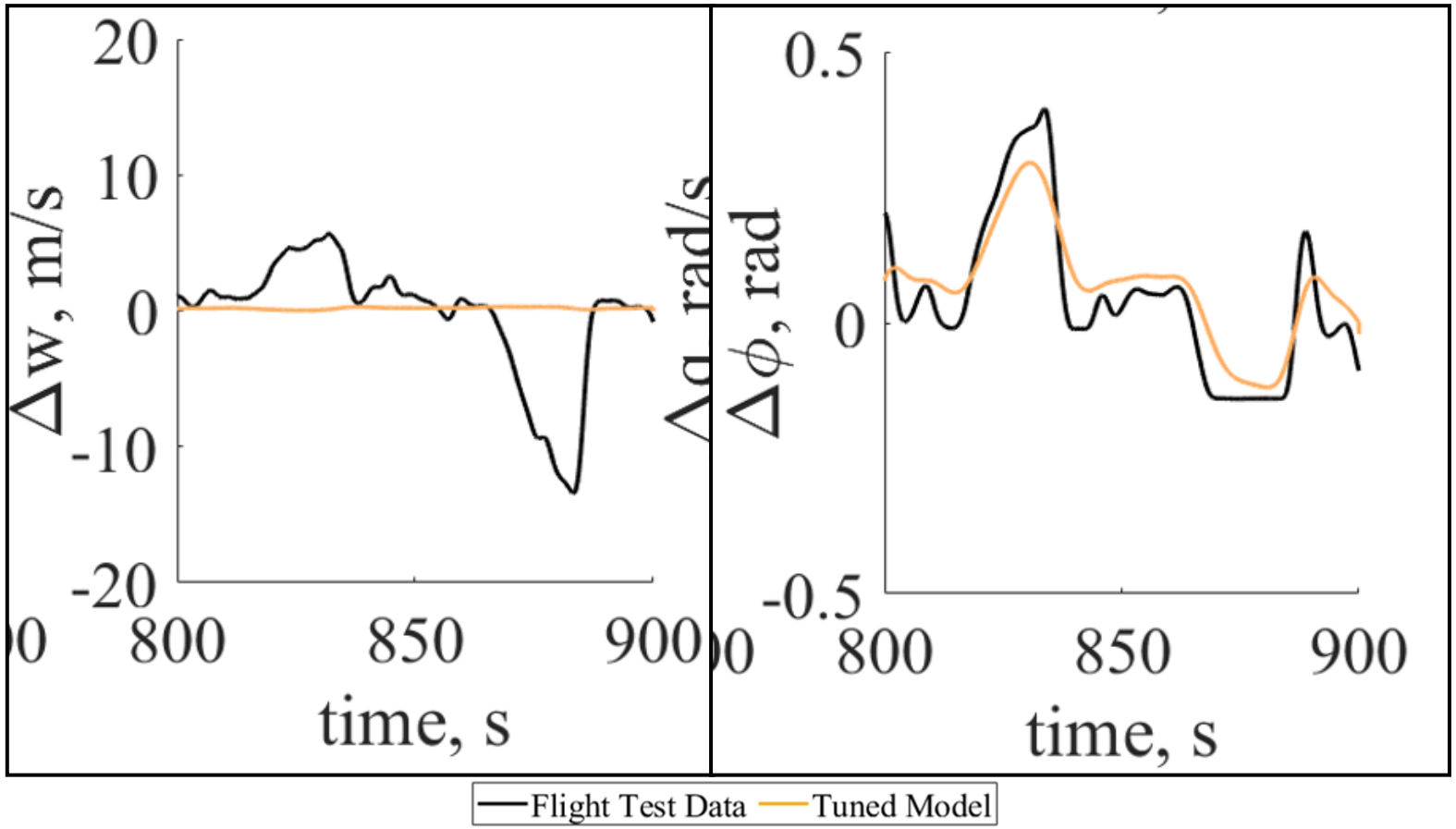
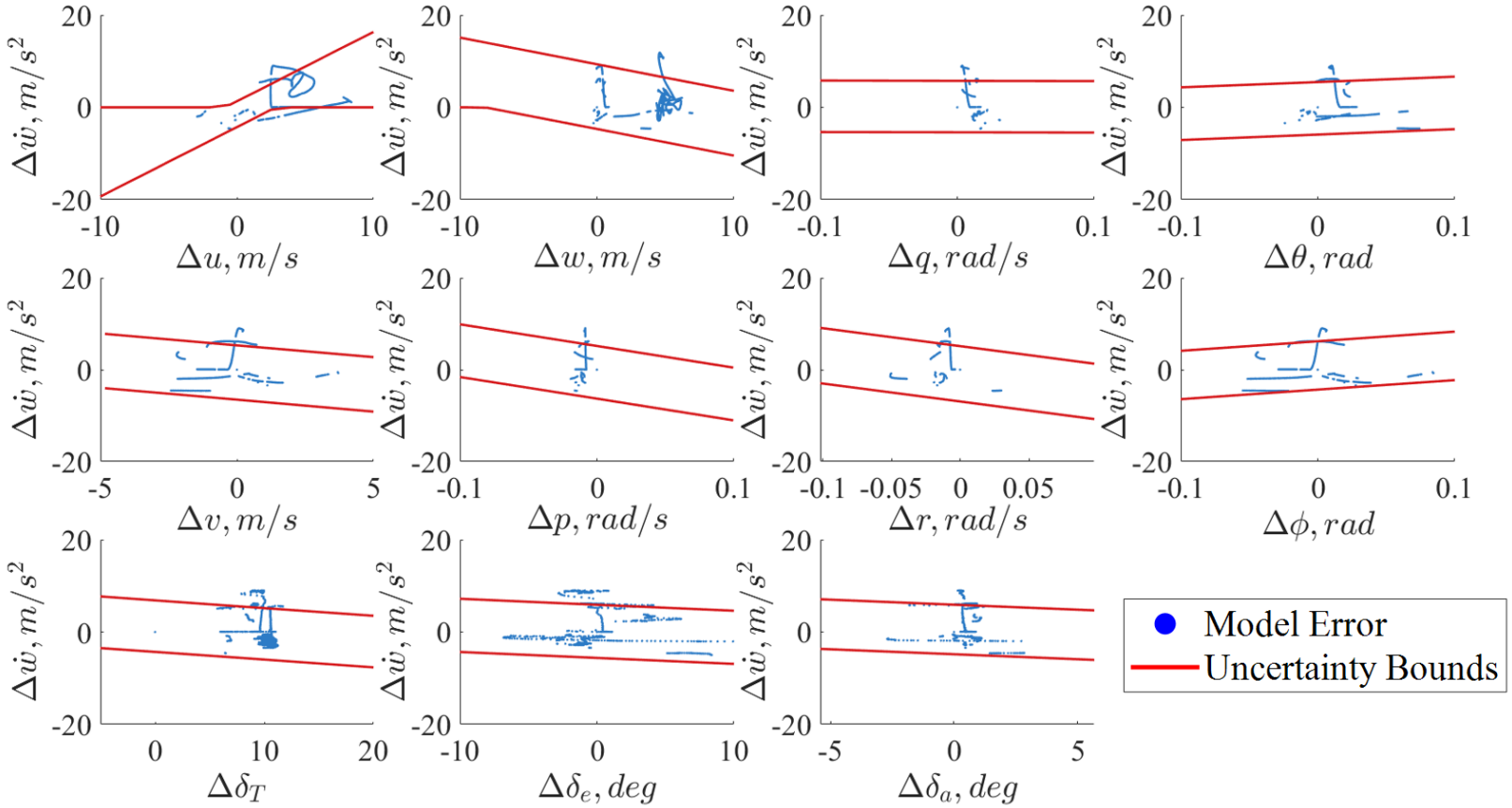


Comparison of flight test data and the tuned model generated from system identification of flight test data

Uncertainty Estimation

- Uncertainty is estimated by comparing the flight test data to the aerodynamic models
- Because of the large amount of flight test data and variation of included maneuvers, the uncertainty remains steady for a wide range of aircraft states



Model error and estimated uncertainty bounds generated using the tuned model

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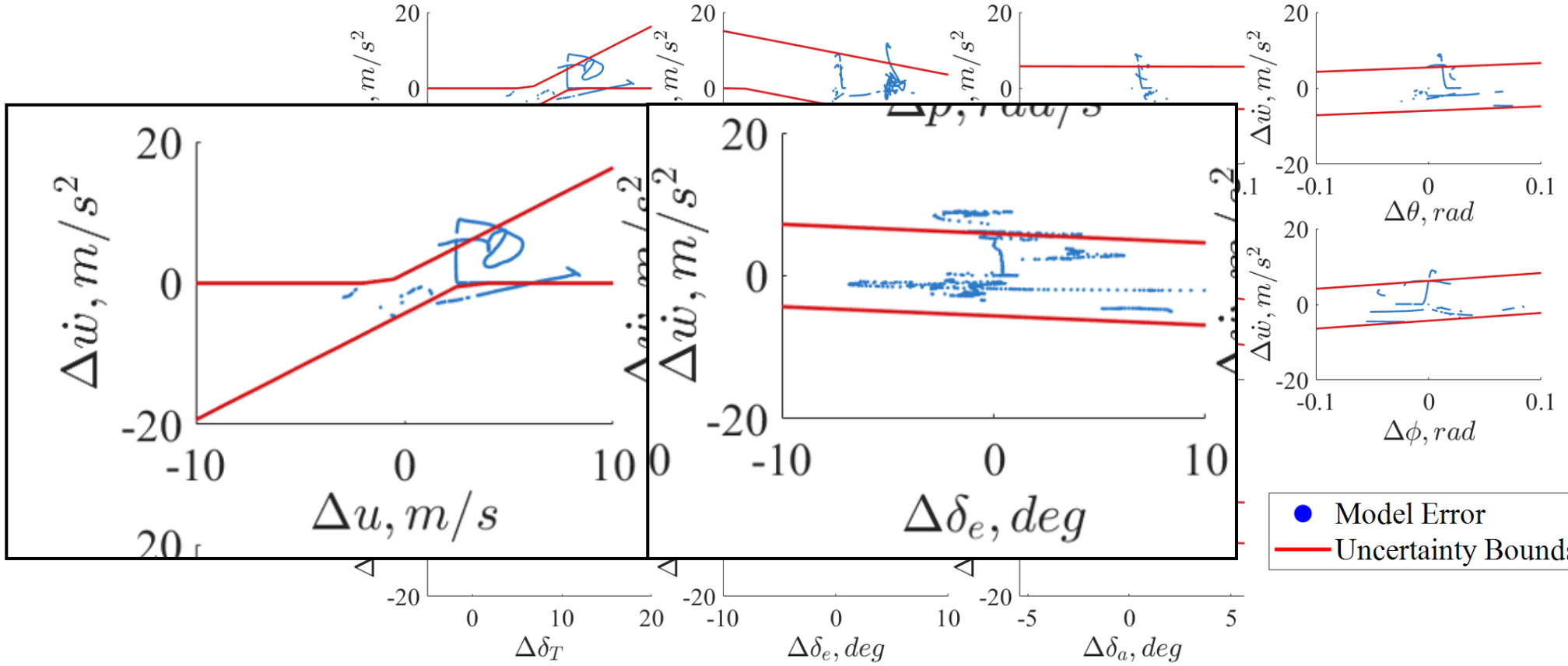
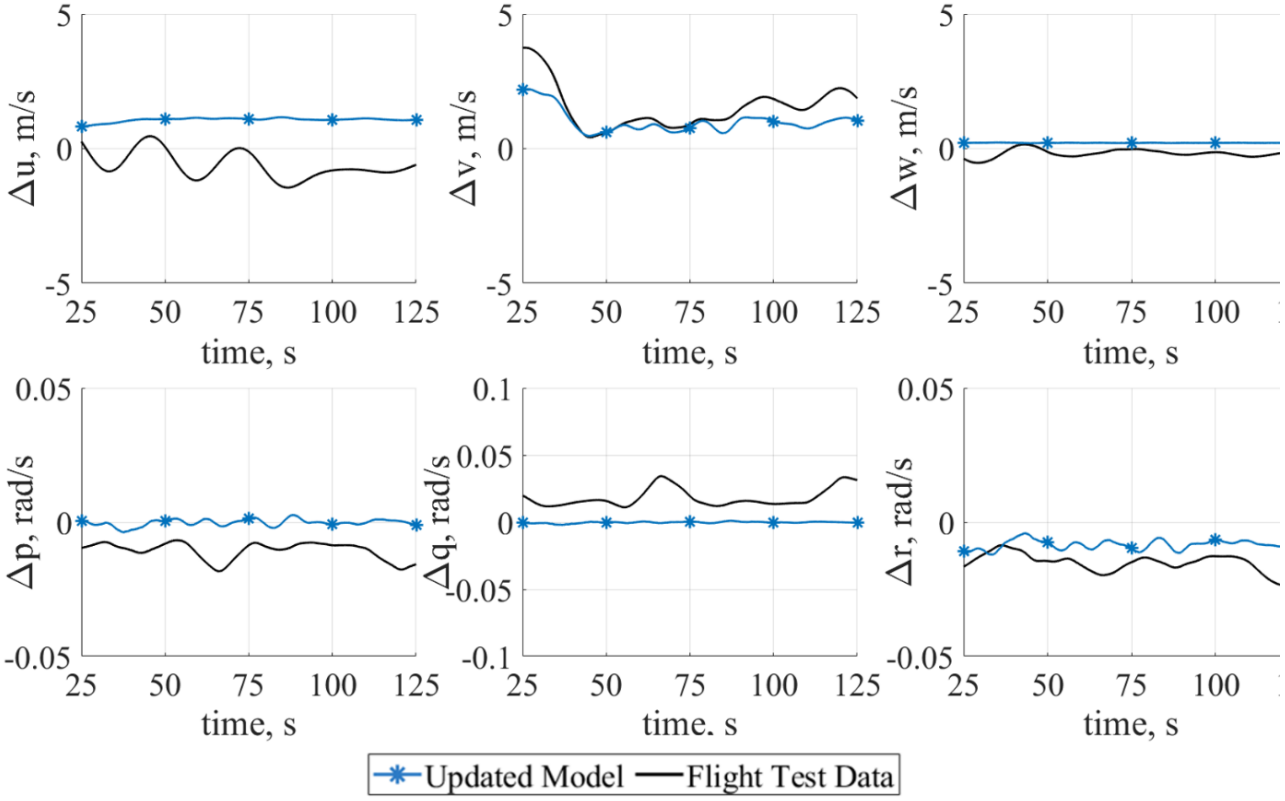


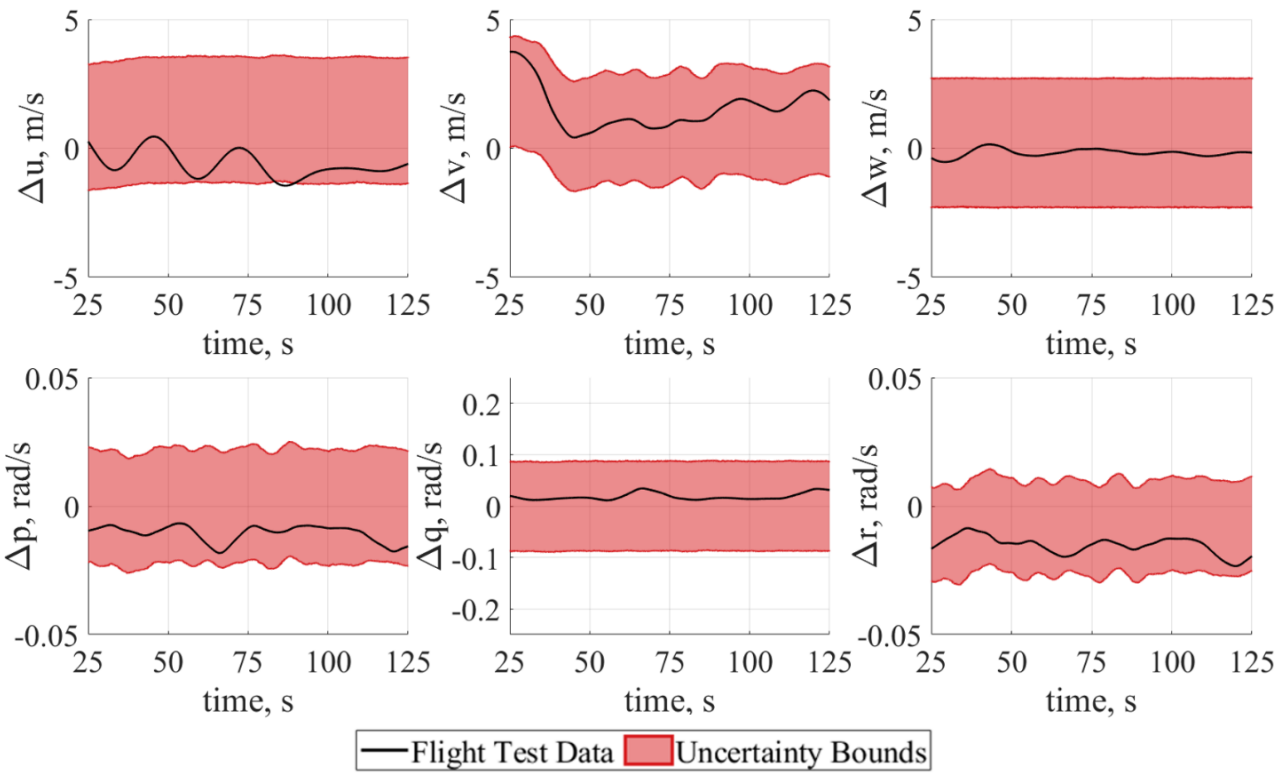
Model error and estimated uncertainty bounds generated using the tuned model

Validation of Nominal Model (Mod-I)

- Before performance of the modified configurations can be predicted, models must be validated for the Mod-I configuration
- Both model and uncertainty are compared to actual flight test data



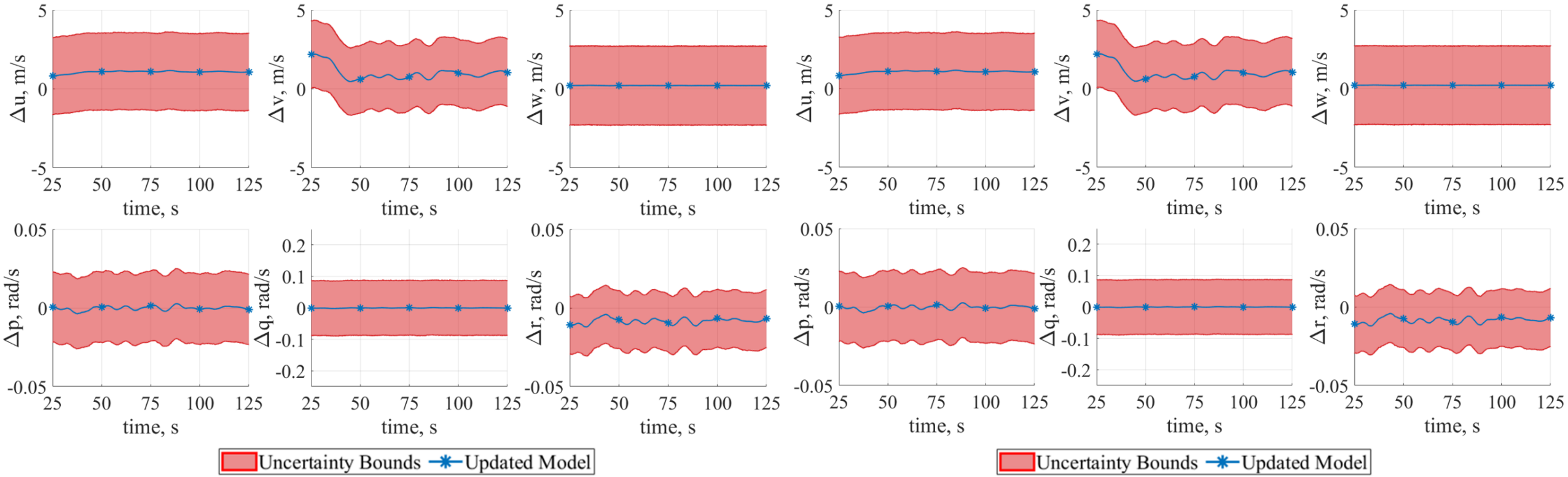
Comparison of the updated model prediction to the flight test data



Comparison of the predicted performance to the flight test data

Performance Prediction for Mod-II and Mod-III Configurations

- Because there is no Mod-II or Mod-III flight test data, results cannot be compared to flight test data and cannot be validated
- Predicted performance between the two is quite similar, due to large impact of noise in flight test data and design of modification



Prediction of Mod-II Performance

Prediction of Mod-III Performance

Summary and Future Work

Summary

- Framework was applied to NASA's X-57 Maxwell, an experimental aircraft with a series of modifications applied to a general aviation aircraft
- Because flight test data is not available for Mod-II and Mod-III, performance estimates cannot be validated

Future Work

- Compare analysis and non-deterministic simulation results for future X-57 flight test data to validate framework for estimating performance of modified aircraft in real-world scenarios
- Continue investigating how this framework could be applied to real-world certification by analysis scenarios