



Wind Tunnel-Based Aerodynamic Model Identification for a Tilt-Wing, Distributed Electric Propulsion Aircraft

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AFM-12/TF-05: Design, Testing, and Modeling for the LA-8 Tilt-Wing VTOL Aircraft II

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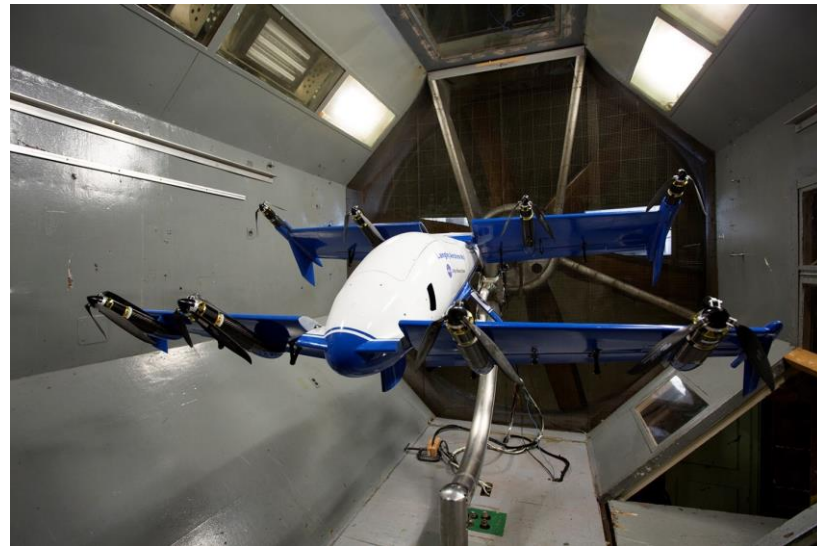
- Motivation
- LA-8 Background
- Modeling approach overview
- Sample results
- Conclusions



Motivation

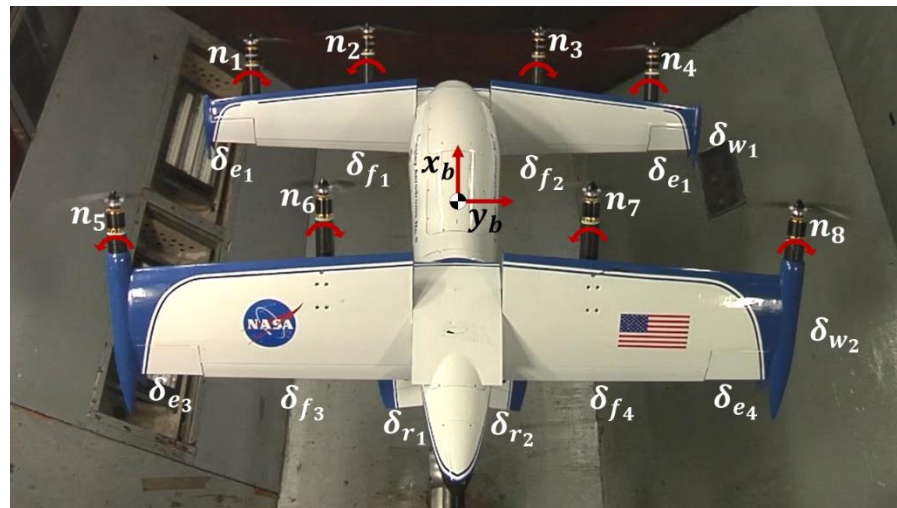


- Develop an aerodynamic model for the LA-8 aircraft suitable for flight dynamics simulation
- Investigate aerodynamic modeling methods for eVTOL vehicles (specifically tilt-wing vehicles)
- eVTOL aircraft modeling challenges
 - Many control surfaces and propulsors
 - Significant airframe-propulsion interactions
 - Model structure is not readily defined
 - Limited intuition into modeling results
 - Drastic changes in aerodynamic characteristics across the flight envelope
 - Reflect aerodynamic characteristics of fixed-wing and rotary-wing aircraft as well as complex vehicle-specific phenomena



**LA-8 aircraft mounted in the NASA Langley
12-Foot Low-Speed Tunnel.**

- LA-8 configuration:
 - Tandem tilt-wing
 - Distributed electric propulsion (DEP)
 - Vertical takeoff and landing (VTOL)
 - 62 lbs, 6 ft wingspan
 - Wind tunnel and flight test research vehicle
- 20 available control effectors
 - Eight, three-bladed 16x8 propellers ($n_1, n_2, \dots, n_8$)
 - Two rotating wings ($\delta_{w_1}, \delta_{w_2}$)
 - Four elevons ($\delta_{e_1}, \delta_{e_2}, \delta_{e_3}, \delta_{e_4}$)
 - Four fowler flaps ($\delta_{f_1}, \delta_{f_2}, \delta_{f_3}, \delta_{f_4}$)
 - Two ruddervators ($\delta_{r_1}, \delta_{r_2}$)



LA-8 propulsor and control surface definitions.

Further information:

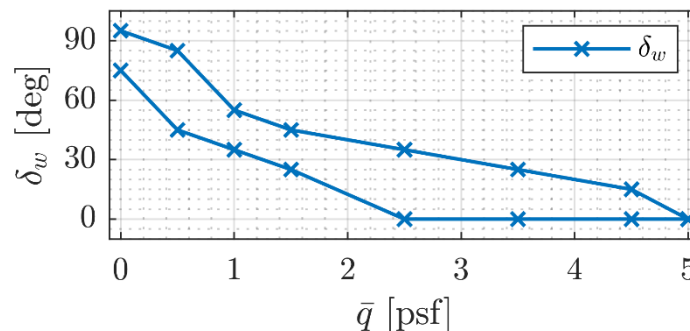
North, D. D., Howland, G., and Busan, R. C., "Design and Fabrication of the LA-8 Distributed Electric Propulsion VTOL Testbed," *AIAA SciTech 2021 Forum*

- Aerodynamic models developed from wind tunnel data
 - Isolated propeller test
 - Powered-airframe DOE test*
- System identification-based approach
 - Aerodynamic models developed at eight tested $\bar{q}$ settings using stepwise regression
 - Factor ranges at each $\bar{q}$ reflect the expected LA-8 flight envelope*
 - Model form tailored to eVTOL vehicles
- Two model identification approaches
 - I. Using only the powered-airframe data
 - II. Synthesizing isolated propeller and powered-airframe data

***Further information:** Busan, R. C., Murphy, P. C., Hatke, D. B., and Simmons, B. M., "Wind Tunnel Testing Techniques for a Tandem Tilt-Wing, Distributed Electric Propulsion VTOL Aircraft," *AIAA SciTech 2021 Forum*



Powered-airframe DOE wind tunnel test.



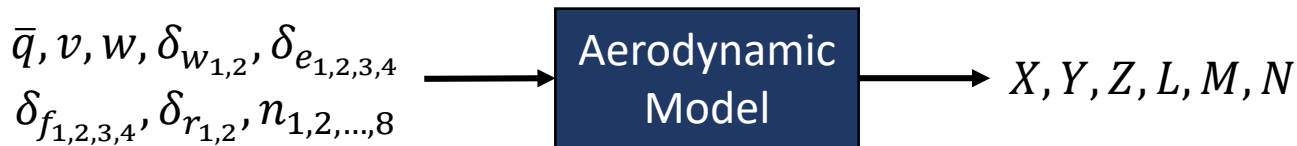
LA-8 DOE wind tunnel test envelope.



I: Model ID Using Only Powered-Airframe Data



- Nonlinear polynomial models developed at each tested $\bar{q}$ from the powered-airframe DOE wind tunnel test
- Response variables:
 - Dimensional body-axis forces: X, Y, Z
 - Dimensional body-axis moments: L, M, N
- Explanatory variables:
 - Body-axis velocity components: v, w $\longrightarrow$ (u effects are captured by models being developed at multiple $\bar{q}$ settings)
 - Wing angles: $\delta_{w_{1,2}}$
 - Control surface deflections: $\delta_{e_{1,2,3,4}}, \delta_{f_{1,2,3,4}}, \delta_{r_{1,2}}$
 - Propeller rotational speed: $n_{1,2,\dots,8}$
- Sample models at $\bar{q} = 3.5$ psf are shown in the paper



LA-8 aerodynamic modeling Approach I.

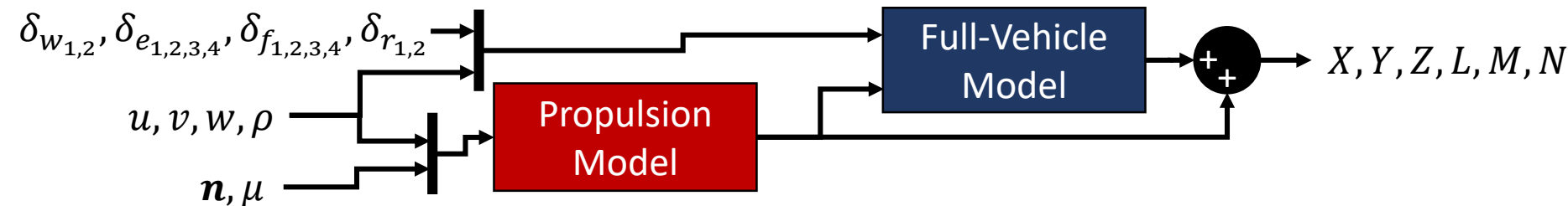
II: Model ID from Multiple Test Data Sets

• Propulsion model

- Nonlinear polynomial model developed from isolated propeller testing across the LA-8 flight envelope
- Outputs estimated propeller forces and moments: T_x , T_y , T_z , Q_x , Q_y , and Q_z
- See: Simmons, B. M., "System Identification for Propellers at High Incidence Angles," *AIAA SciTech 2021 Forum*

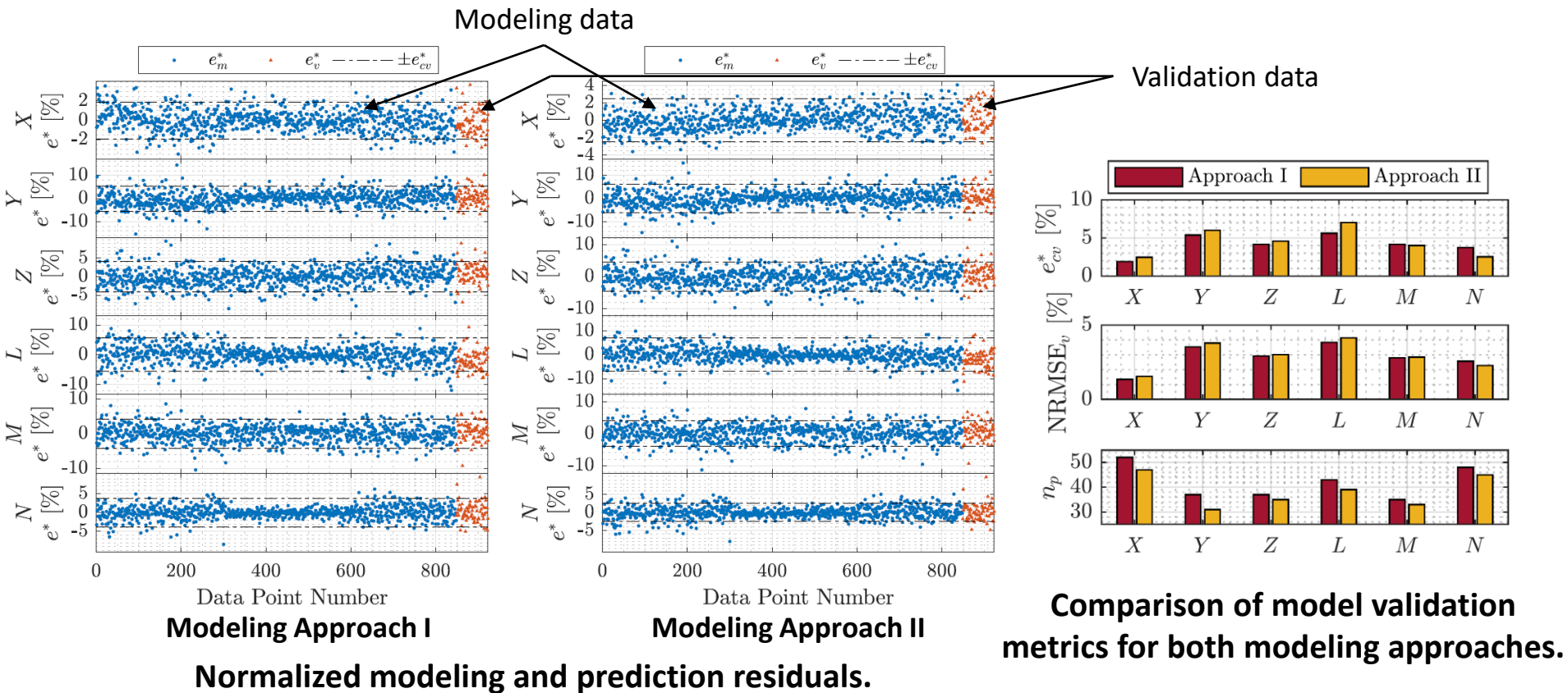
• Full-vehicle model

- Nonlinear polynomial model developed from powered-airframe DOE test data at each tested $\bar{q}$
- Response variables: dimensional body-axis forces and moments are subtracted from estimated propeller forces and moments
 - $\hat{X} = X - \sum_{k=1}^8 T_{x_k}^b$, $\hat{Y} = Y - \sum_{k=1}^8 T_{y_k}^b$, $\hat{Z} = Z - \sum_{k=1}^8 T_{z_k}^b$
 - $\hat{L} = L - \sum_{k=1}^8 Q_{x_k}^b$, $\hat{M} = M - \sum_{k=1}^8 Q_{y_k}^b$, $\hat{N} = N - \sum_{k=1}^8 Q_{z_k}^b$
- Explanatory variables: v , w , $\delta_{w_{1,2}}$, $\delta_{e_{1,2,3,4}}$, $\delta_{f_{1,2,3,4}}$, $\delta_{r_{1,2}}$, $T_{1,2,...,8}$



LA-8 aerodynamic modeling Approach II.

Sample LA-8 Modeling Results at $\bar{q} = 3.5 \text{ psf}$





- eVTOL aircraft present new challenges for aircraft modeling
 - eVTOL vehicle characteristics overlap with fixed-wing and rotary-wing aircraft, but also include vehicle specific phenomena
 - Many control effectors and complex vehicle interactions result in challenges postulating an adequate model structure
- Modeling approaches developed for eVTOL vehicles were successful
 - A unique set of modeling explanatory variables and response variables tailored specifically to tilt-wing, DEP aircraft were proposed
 - Both proposed modeling approaches yielded good predictive capability and small fit error
- The LA-8 flight dynamics simulation enables eVTOL and UAM research for many other disciplines



Questions – Thank you for your attention.



Acknowledgments

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Design, Testing, and Modeling for the LA-8 Tilt-Wing VTOL Aircraft I & II References

1. North, D. D., Howland, G., and Busan, R. C., “Design and Fabrication of the LA-8 Distributed Electric Propulsion VTOL Testbed”
2. Busan, R. C., Murphy, P. C., Hatke, D. B., and Simmons, B. M., “Wind Tunnel Testing Techniques for a Tandem Tilt-Wing, Distributed Electric Propulsion VTOL Aircraft”
3. Simmons, B. M., “System Identification for Propellers at High Incidence Angles”
4. Geuther, S. C., and Fei, X., “LA-8 Computational Analysis and Validation Studies Using FlightStream”
5. **Simmons, B. M., and Murphy, P. C., “Wind Tunnel-Based Aerodynamic Model Identification for a Tilt-Wing, Distributed Electric Propulsion Aircraft”**
6. North, D. D., “Flight Testing of a Scale Urban Air Mobility Technology Testbed” (Presentation Only)