Rapid Aero Modeling for Urban Air Mobility Aircraft in Computational Experiments

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2021 AIAA SciTech Forum

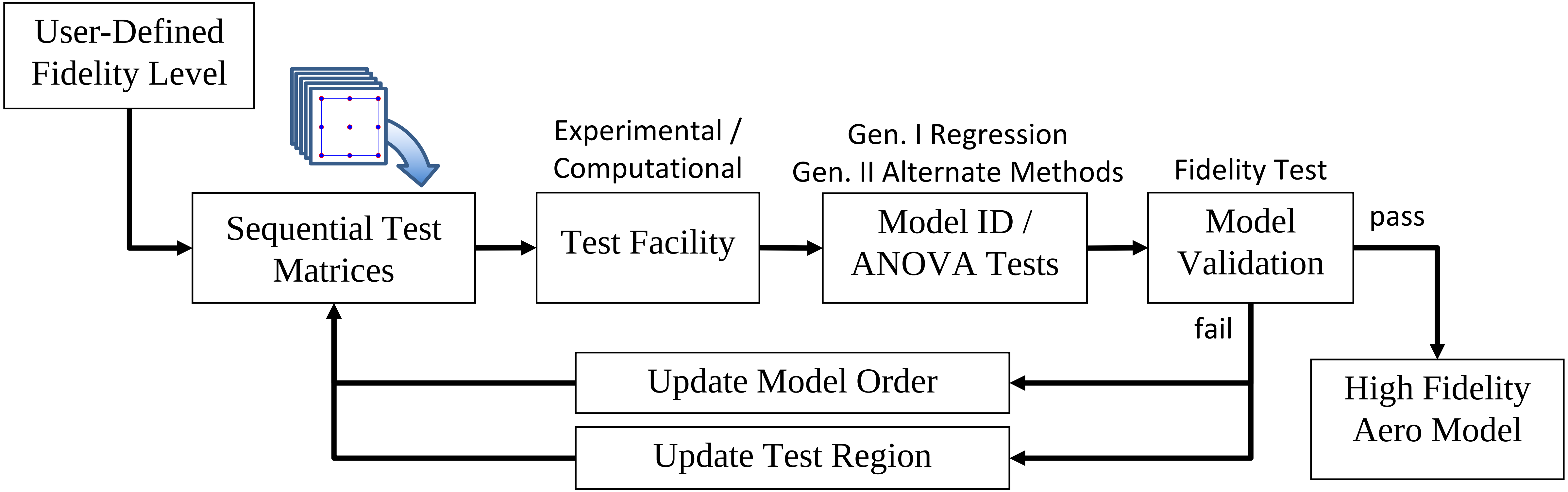
January 14, 2021

Motivation for Rapid Aero Modeling (RAM)

- Challenges in Urban Air Mobility Transportation Systems:
  - Aircraft features
    - Hybrid aircraft-rotorcraft.
    - Complexity, nonlinearity, and large numbers of interacting factors.
  - Conventional test methods (one-factor-at-a-time testing)
    - Fail to capture the complexity and numerous interactions.
    - Results in costly studies in terms of time and resources.
    - Produces models with limited information.
- Objectives:
  - Produce models suitable for nonlinear flight dynamics simulations.
  - Develop automated testing process.
  - Take advantage of well-established experiment design methods.

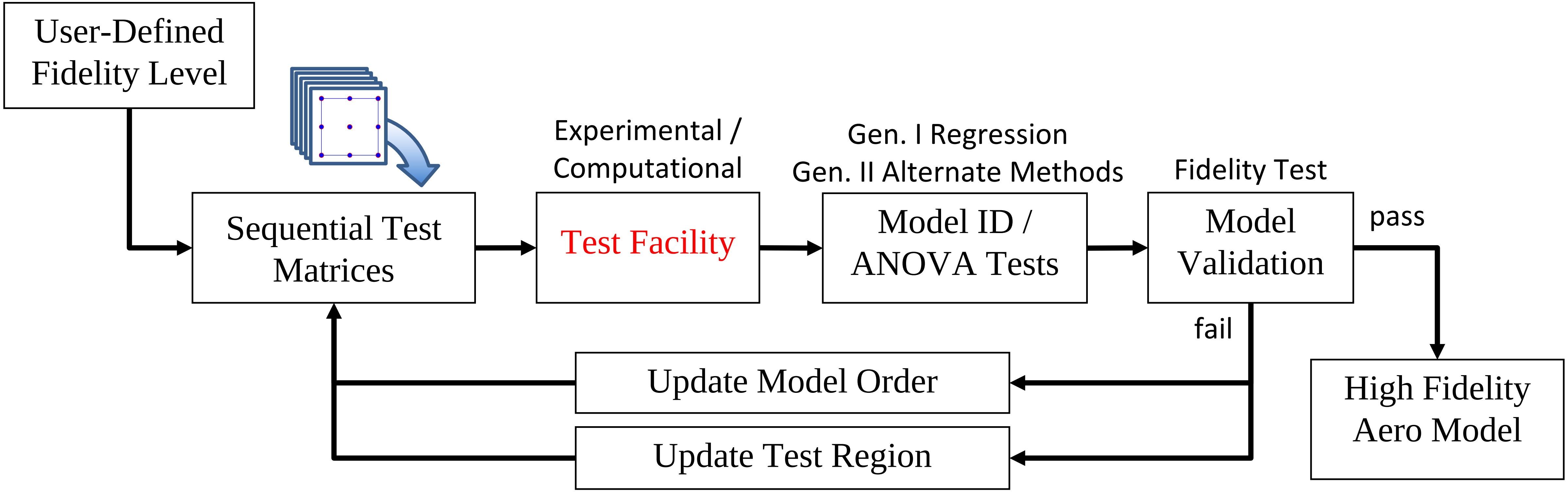
Rapid Aero Modeling (RAM) Process - Introduction

- RAM provides an automated, run efficient, statistically rigorous, testing process.
- Fidelity levels defined for each aero coefficient in terms of prediction error.



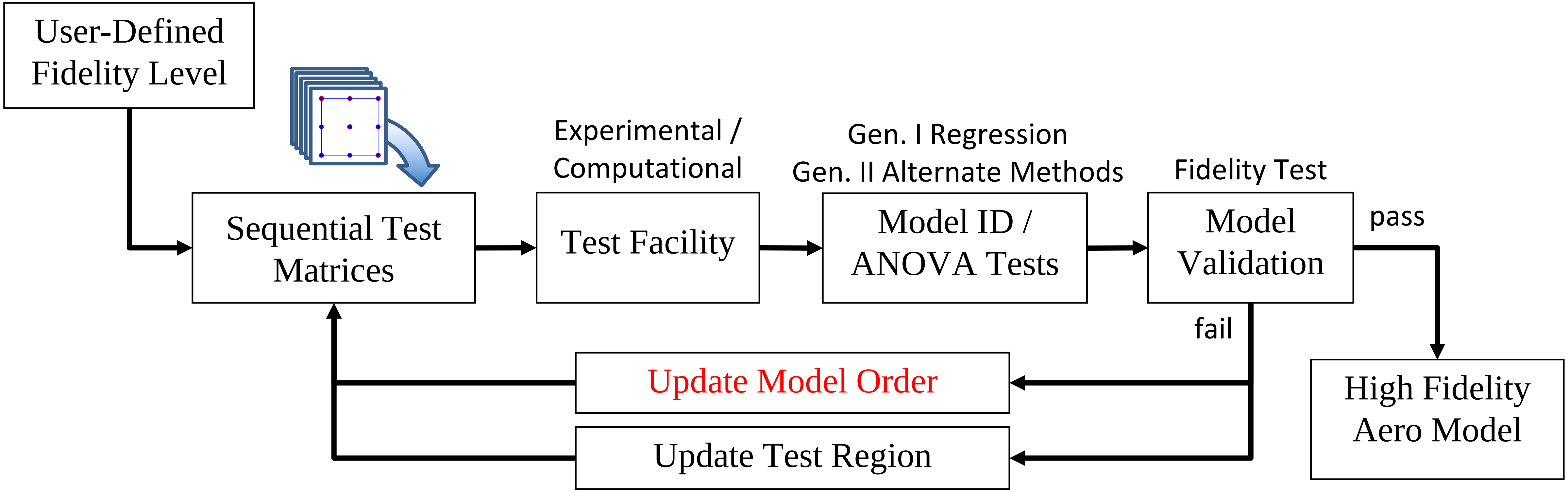
Rapid Aero Modeling (RAM) Process – Test Facilities

- First applications to static wind-tunnel (RAM-T) and computational experiments (RAM-C).



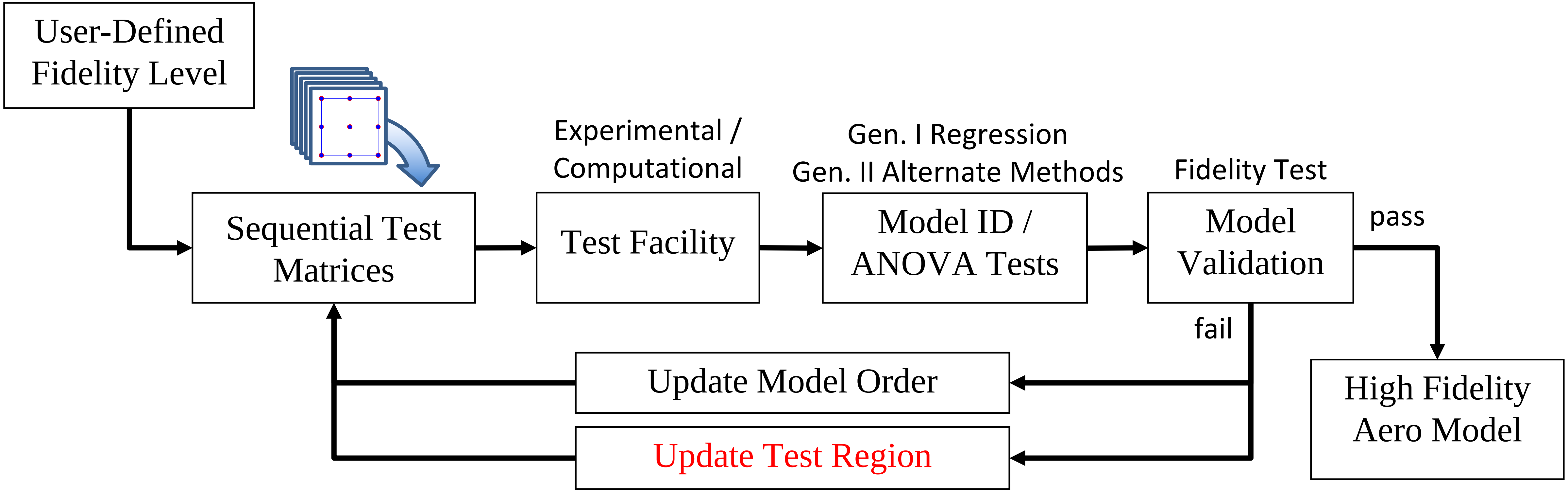
Rapid Aero Modeling (RAM) Process – Inner Loop

- New data blocks requested only as needed to satisfy more complex polynomial models.



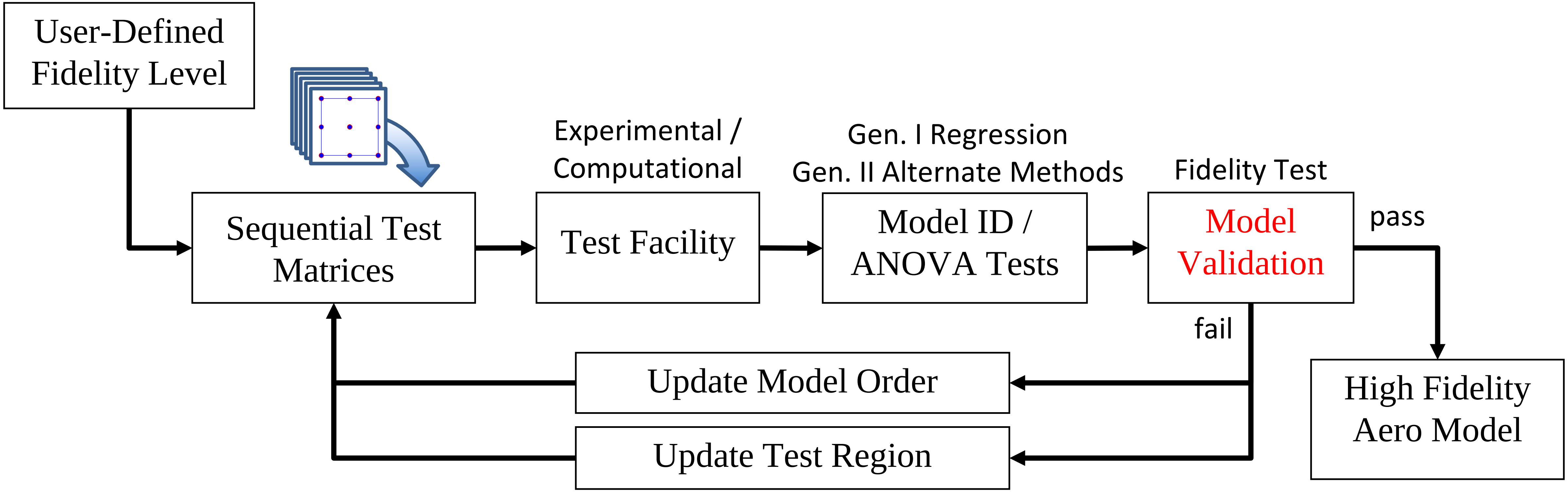
Rapid Aero Modeling (RAM) Process – Outer Loop

- Test region is split when validation fails with highest-order polynomial.

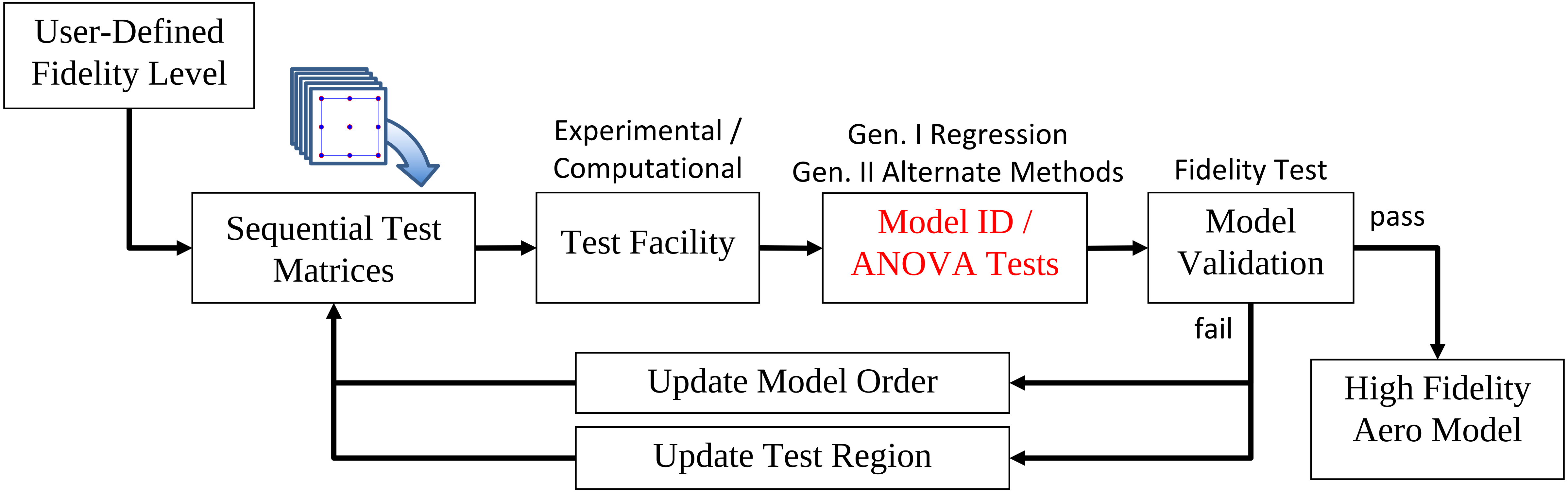


Rapid Aero Modeling (RAM) Process – Model Validation

- Data for validation are not used for model identification.

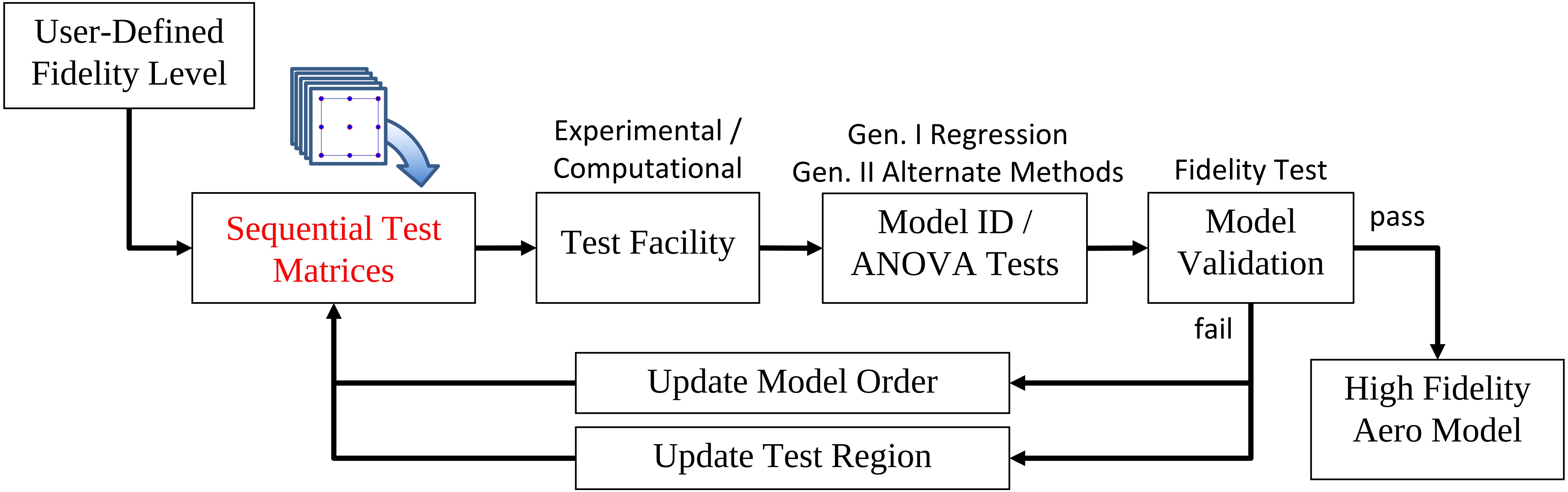


- Stepwise regression is used for Model ID.



Rapid Aero Modeling (RAM) Process – Test Matrices

- RAM Block Library of test matrices based on DOE/RSM theory.

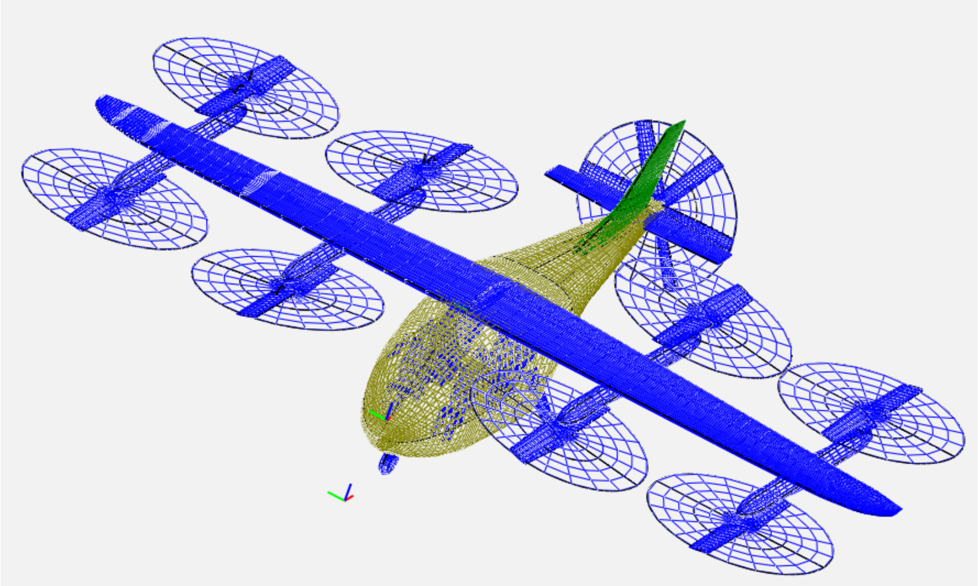


RAM-C Example Applications

- “Test Facility” – OVERFLOW, a NASA developed high-fidelity CFD flow solver.
- Rotorcraft airfoil, 2-factor study
  - Mach number and angle of attack
  - Large factor ranges demonstrate splitting
- L+C, 17-factor study
  - 3 Body-axis velocities: u, v, w
  - 5 Control surfaces: LA, RA, LE, RE, RUD
  - 8 Rotors: N1-N8
  - 1 Pusher propeller: N9

Rotor Airfoil (SSC-A09)

Lift+Cruise (L+C) Configuration



Basic Block Designs & Supported Models – 2-factor Case

- Full factorial design

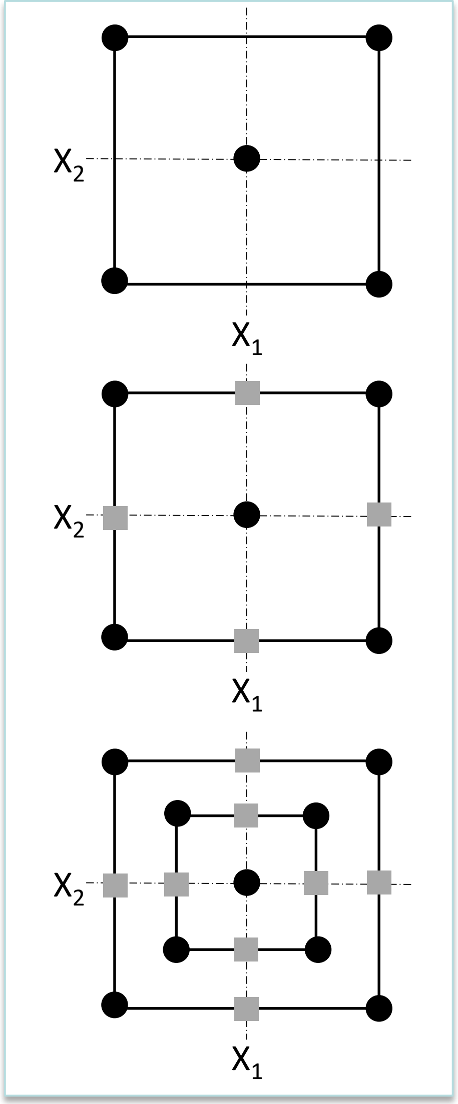
$$y = B_0 + \sum_i B_i x_i + \sum_{i \neq j}\sum B_{ij} x_i x_j + ... + \varepsilon \qquad i = 1, 2, ..., k$$

- Face-centered design (FCD) – *RAM Block #1*

$$y = B_0 + \sum_i B_i x_i + \sum_i B_{ii} x_i^2 + \sum_{i \neq j}\sum B_{ij} x_i x_j + \varepsilon \qquad i = 1, 2, ..., k$$

- Nested face-centered design – *RAM Blocks #1 & #2*

$$y = B_0 + \sum_i B_i x_i + \sum_i B_{ii} x_i^2 + \sum_{i \neq j}\sum B_{ij} x_i x_j + \sum_i B_{iii} x_i^3 + \varepsilon \qquad i = 1, 2, ..., k$$



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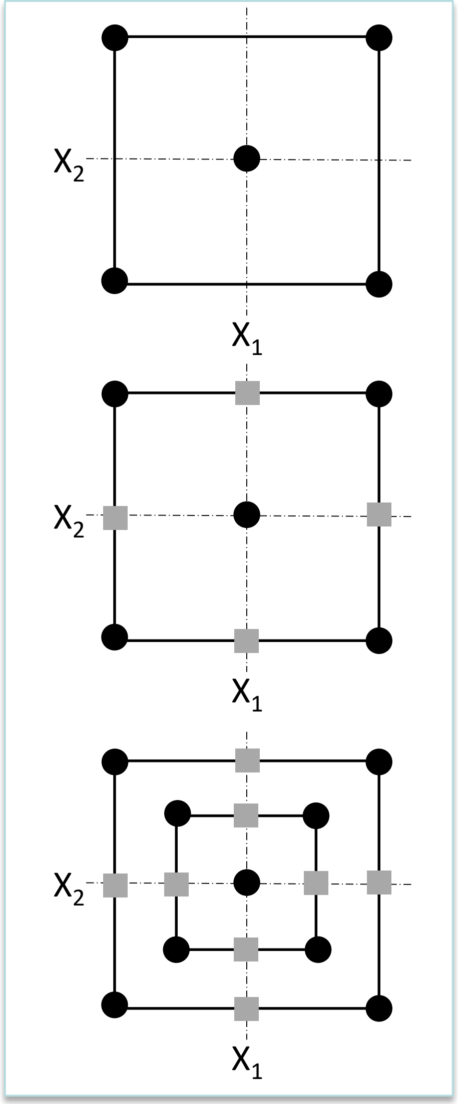

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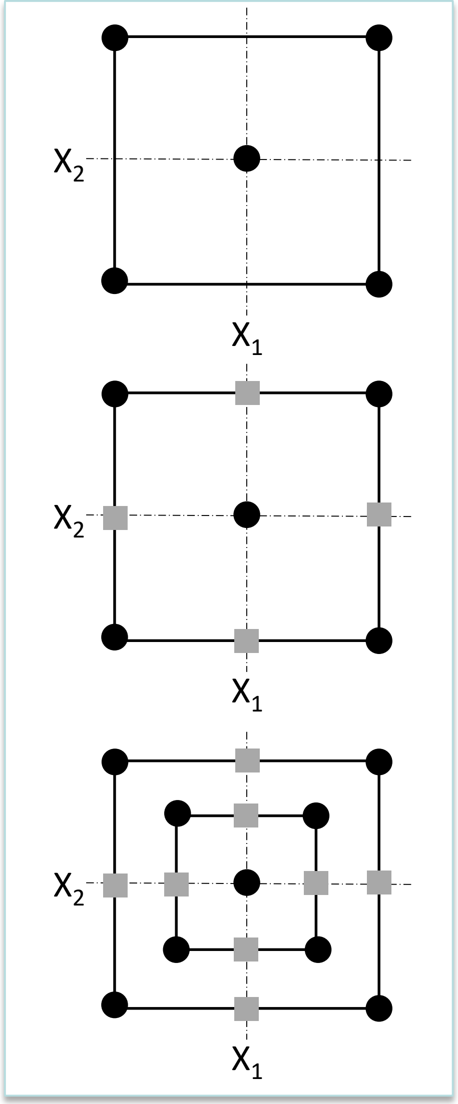
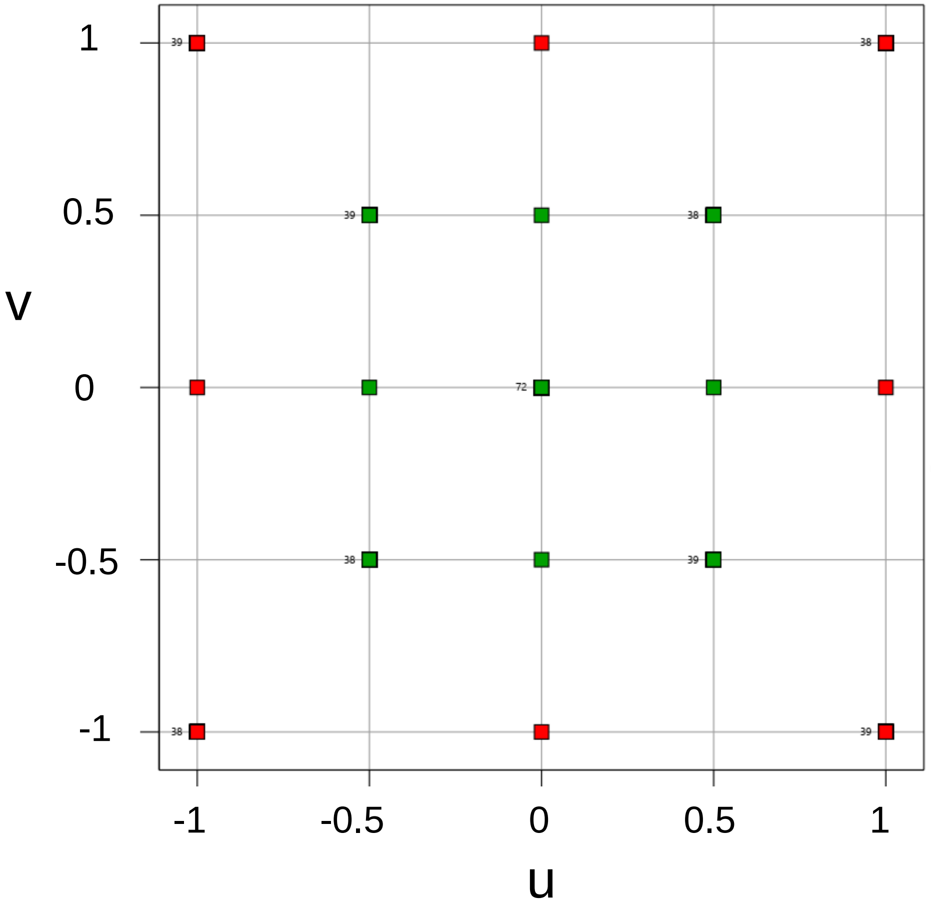


RAM Design for L+C, 17-factor Test

- 17-Factors: u, v, w, LA, RA, LE, RE, RUD, N1-N9
- 5-blocks (factors are scaled to +/- 1), 858 test points

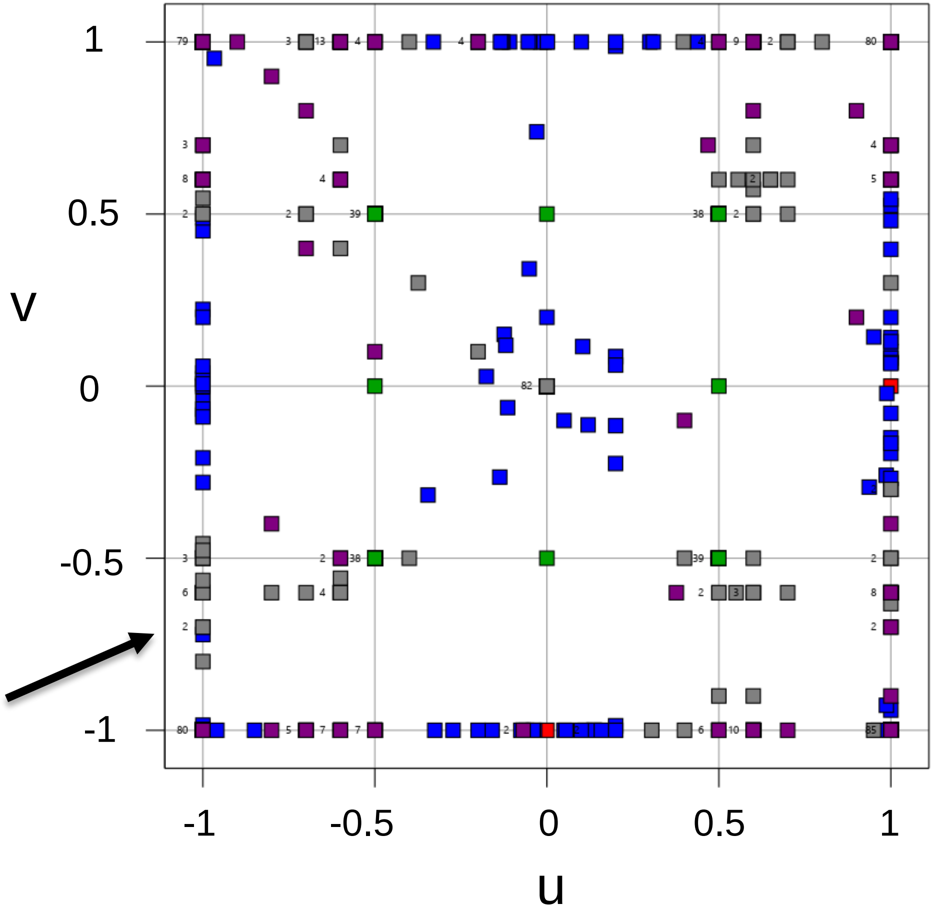
Block 1 – FCD
Block 2 – nested FCD



Block Colors
1
2
3
4
5

Blocks 1-2

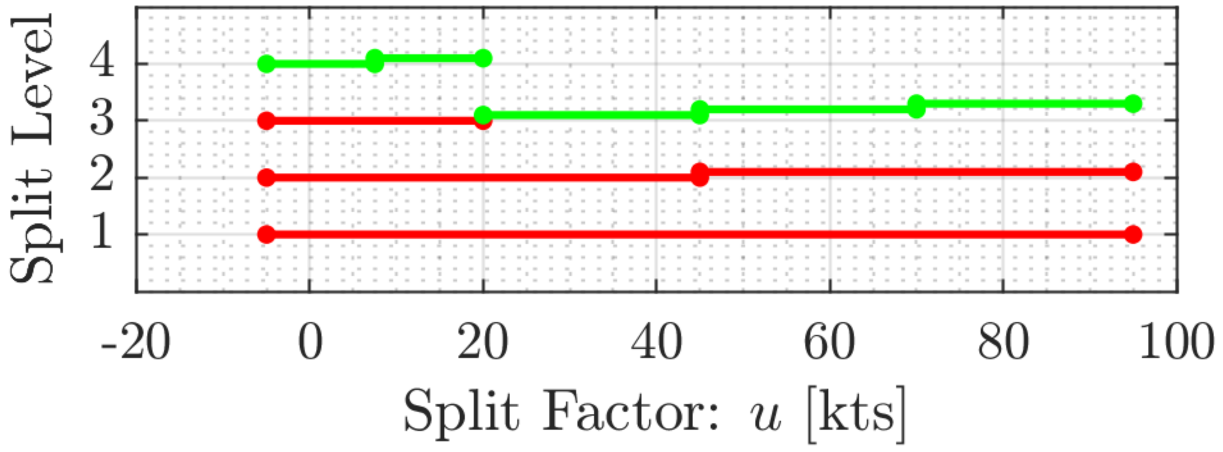
Blocks 3-4 – optimized for minimum PE
Block 5 – validation test data



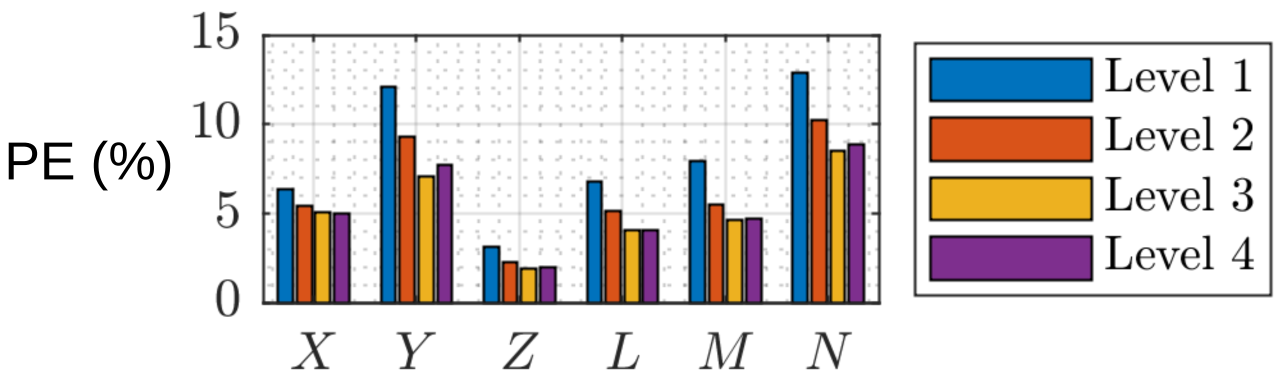
Blocks 1-5

Speed-Regime Splits & PE Metric for L+C Study

- Test regions are split when models fail prediction goals.
  - Satisfactory model – green bars.
  - Unsatisfactory model – red bars.



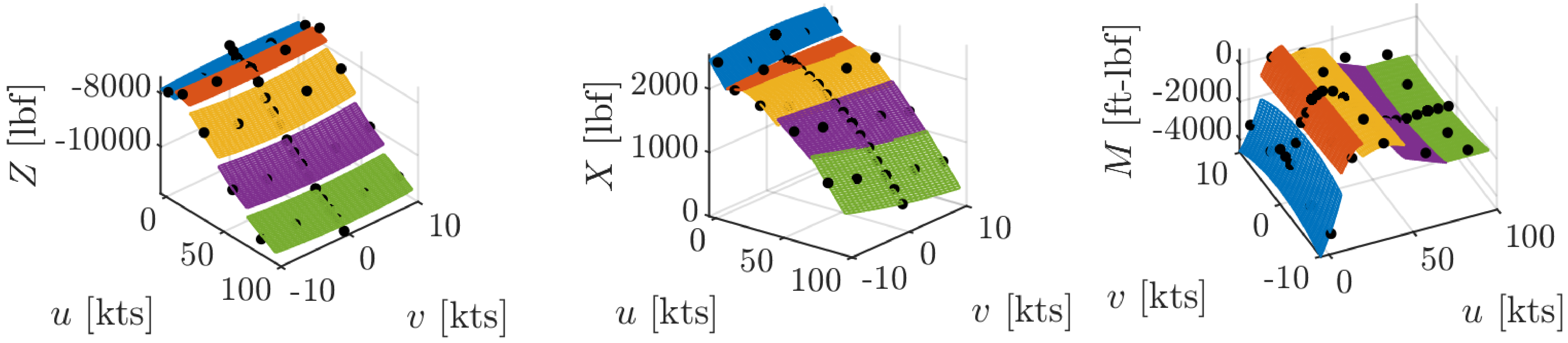
- Regions are halved to improve data density & model fidelity.



- In final analysis for L+C study, 4 split levels were required, resulting in 5 separate modeling regions.

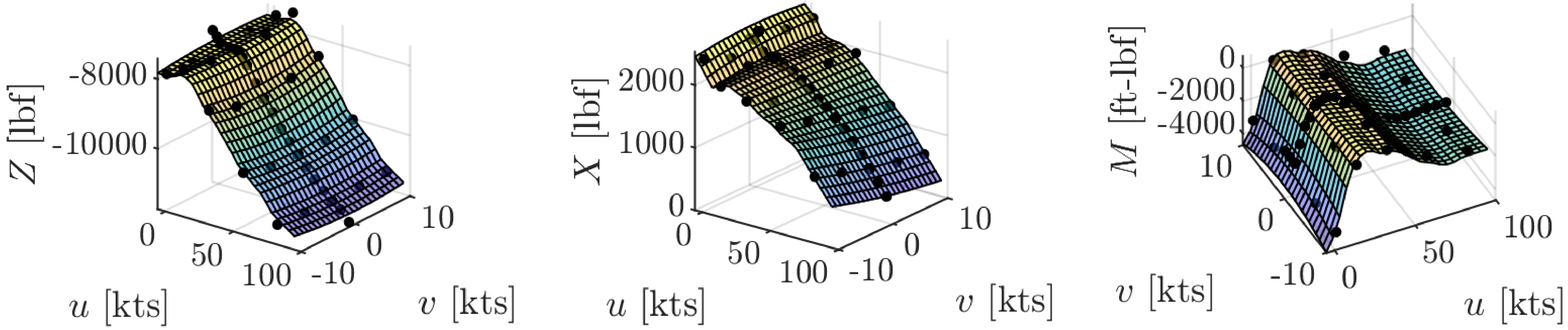
Split-Region Models

- L+C Longitudinal response models for separate regions as functions of (u, v).



Blended Models

- L+C Final global longitudinal response models as functions of (u, v).



Concluding Remarks

- RAM Motivation – complexity, factor count, interactions, and aero nonlinearities.
- RAM Process – automated, run efficient, and statistically rigorous testing.
- RAM Objective – desired model fidelity with limited data, save time and resources.
- RAM Applications – tunnel (RAM-T) or computational (RAM-C) test environments.
- RAM Demonstration – RAM-C applied to two computational experiments.

Questions

- Author Contact Information

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  - P. G. Buning, Pieter.G.Buning@nasa.gov
  - B. M. Simmons, Benjamin.M.Simmons@nasa.gov

- Related papers

  - Murphy, P. C., Simmons, B. M., Hatke, D. B., Busan, R. C., “Rapid Aero Modeling for Urban Air Mobility Aircraft in Wind-Tunnel Tests,” *AIAA SciTech 2021 Forum*, January 2021.
  - 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 Forum*, January 2021.
  - Simmons, B. M., and Murphy, P. C. “Wind Tunnel-Based Aerodynamic Model Identification for a Tilt-Wing, Distributed Electric Propulsion Aircraft,” *AIAA SciTech 2021 Forum*, January 2021.
  - Simmons, B. M. “System Identification for Propellers at High Incidence Angles,” *AIAA SciTech Forum*, January 2021.

- Acknowledgments

  - The authors extend their appreciation to NASA Transformational Tools and Technologies and Revolutionary Vertical Lift Technologies Projects. Numerical simulations were performed using the NASA Advanced Supercomputing (NAS) System and the NASA Langley Research Center Mid-Range Computing Cluster.
