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# SPACE LAUNCH SYSTEM

09/21/2020

## SLS Aerodynamics: Progress toward fusion of CFD and Wind Tunnel Data

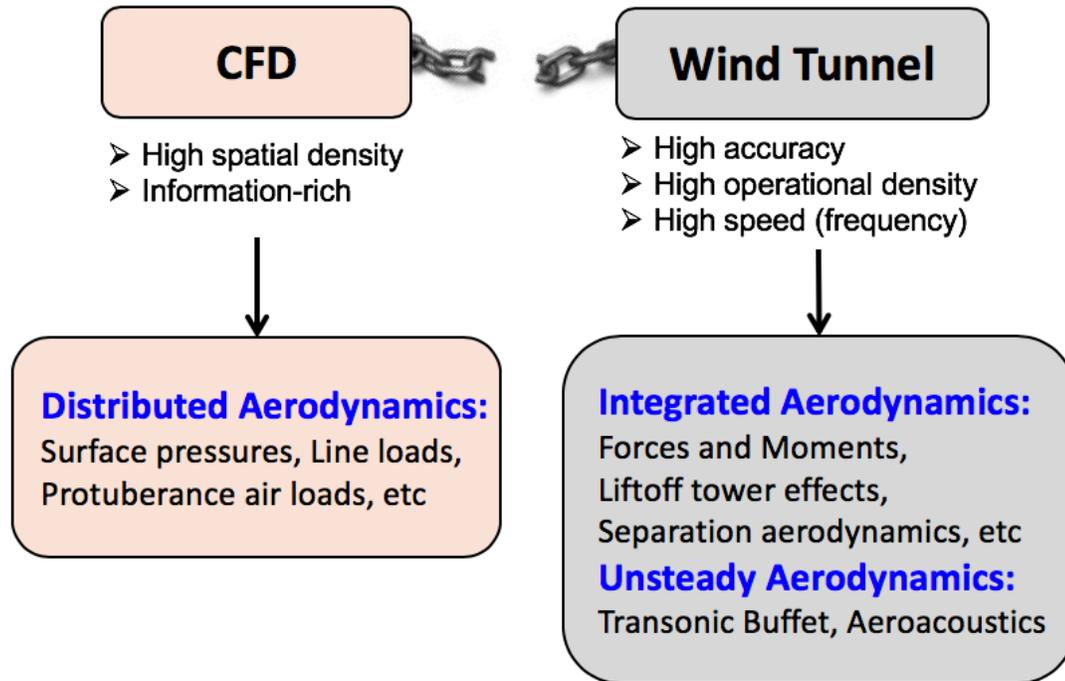
Dr. Jeremy Pinier, Dr. Patrick Shea, T.J. Wignall

SLS Aerodynamics Task Team, Langley/D301



# A NEW APPROACH

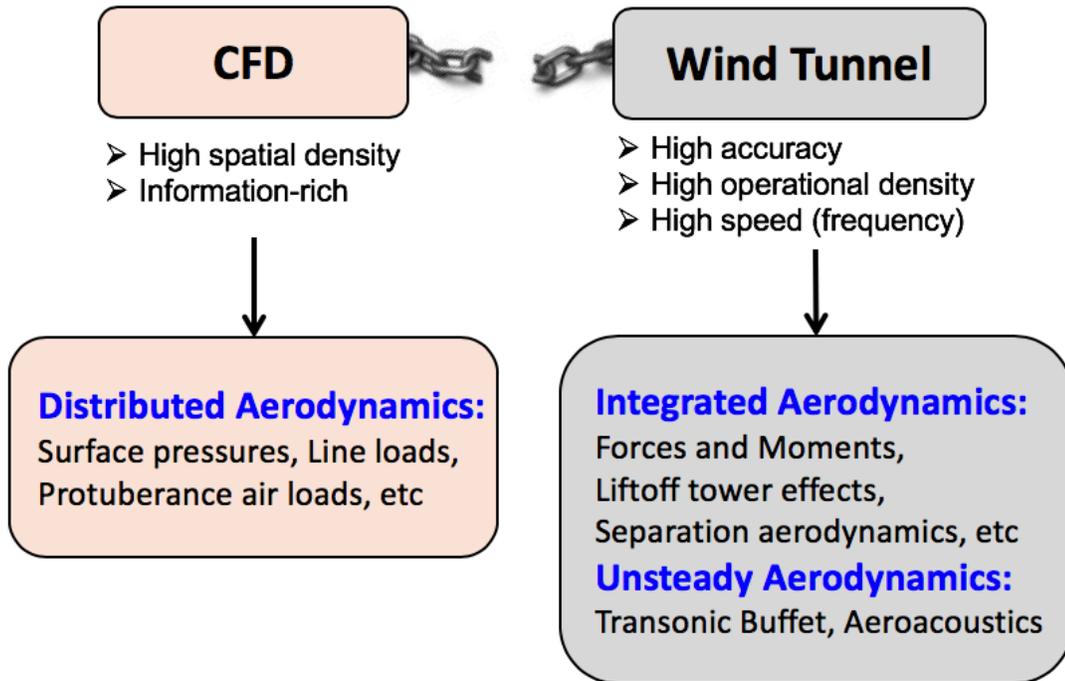
## Traditional



- **Discrete** Aerodynamic Models
- **Inconsistencies** between distributed and integrated aerodynamics

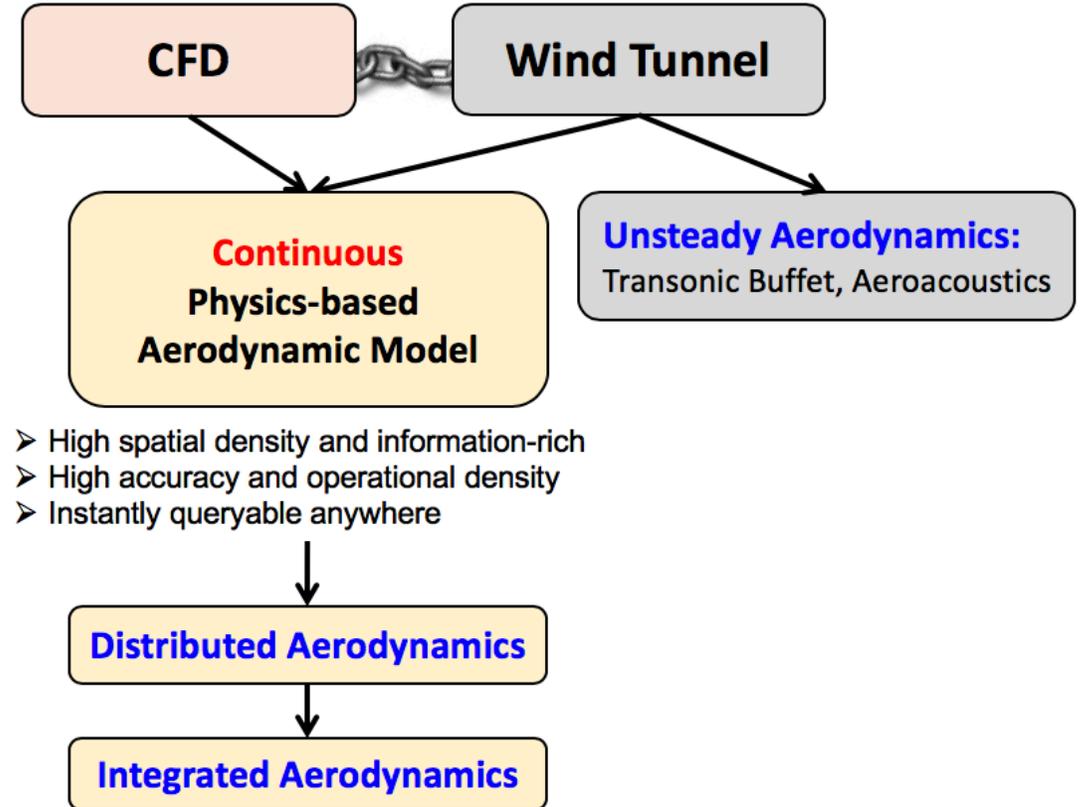
# A NEW APPROACH

## Traditional



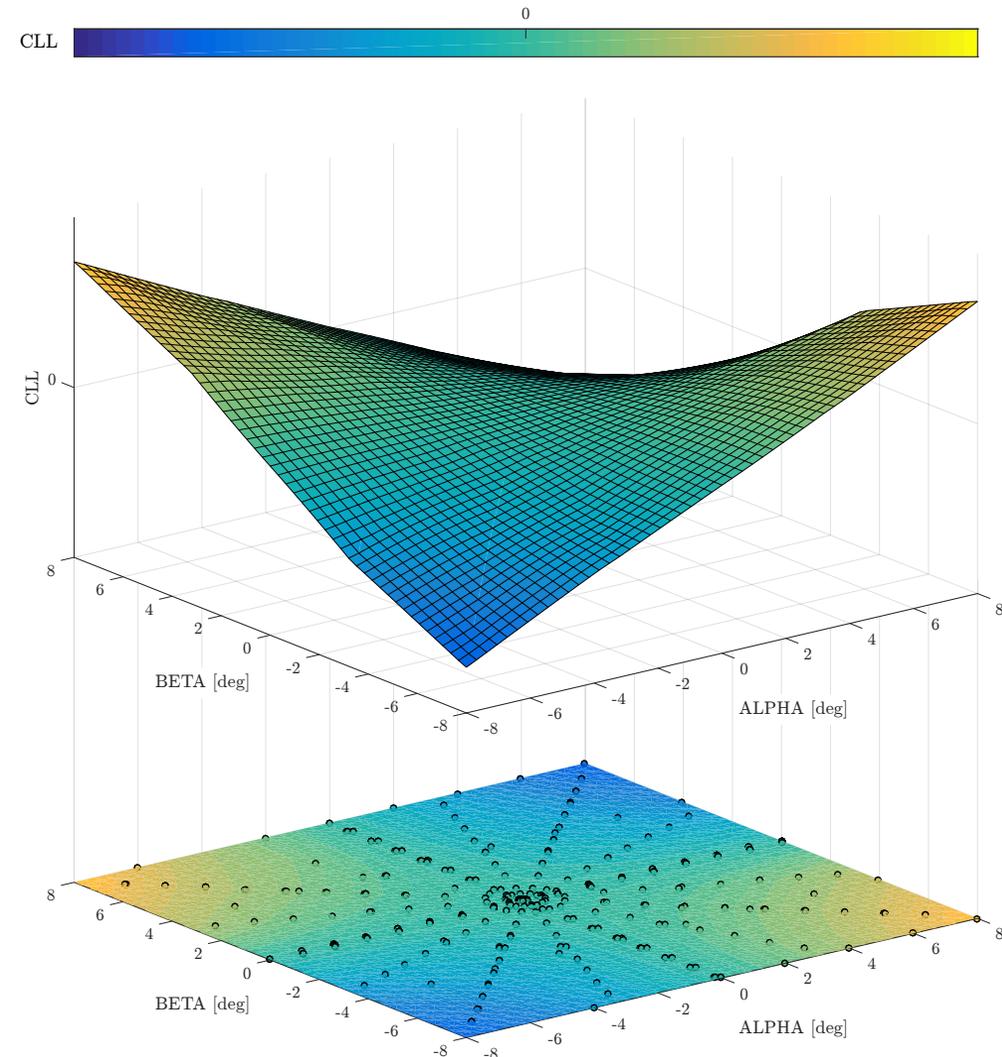
- **Discrete** Aerodynamic Models
- **Inconsistencies** between distributed and integrated aerodynamics

## Data Fusion



# RESPONSE SURFACE MODELING

- **SLS utilizes numerous modeling techniques selected based on the database being developed**
- **Limited degrees of freedom**
  - Example
    - Ascent forces and moments (AIAA Paper 2019-3298)
  - Tools
    - Traditional interpolation techniques
      - Linear; Natural; Thin-plate Splines
    - Typically implemented as two-dimensional interpolation (2 inputs; 1 output)
  - Advantages
    - Robust
      - Response surfaces unlikely to have erratic behavior
    - Methodology is well documented and easily defensible
  - Weaknesses
    - Difficult to adapt to higher DOF databases with four or more independent variables



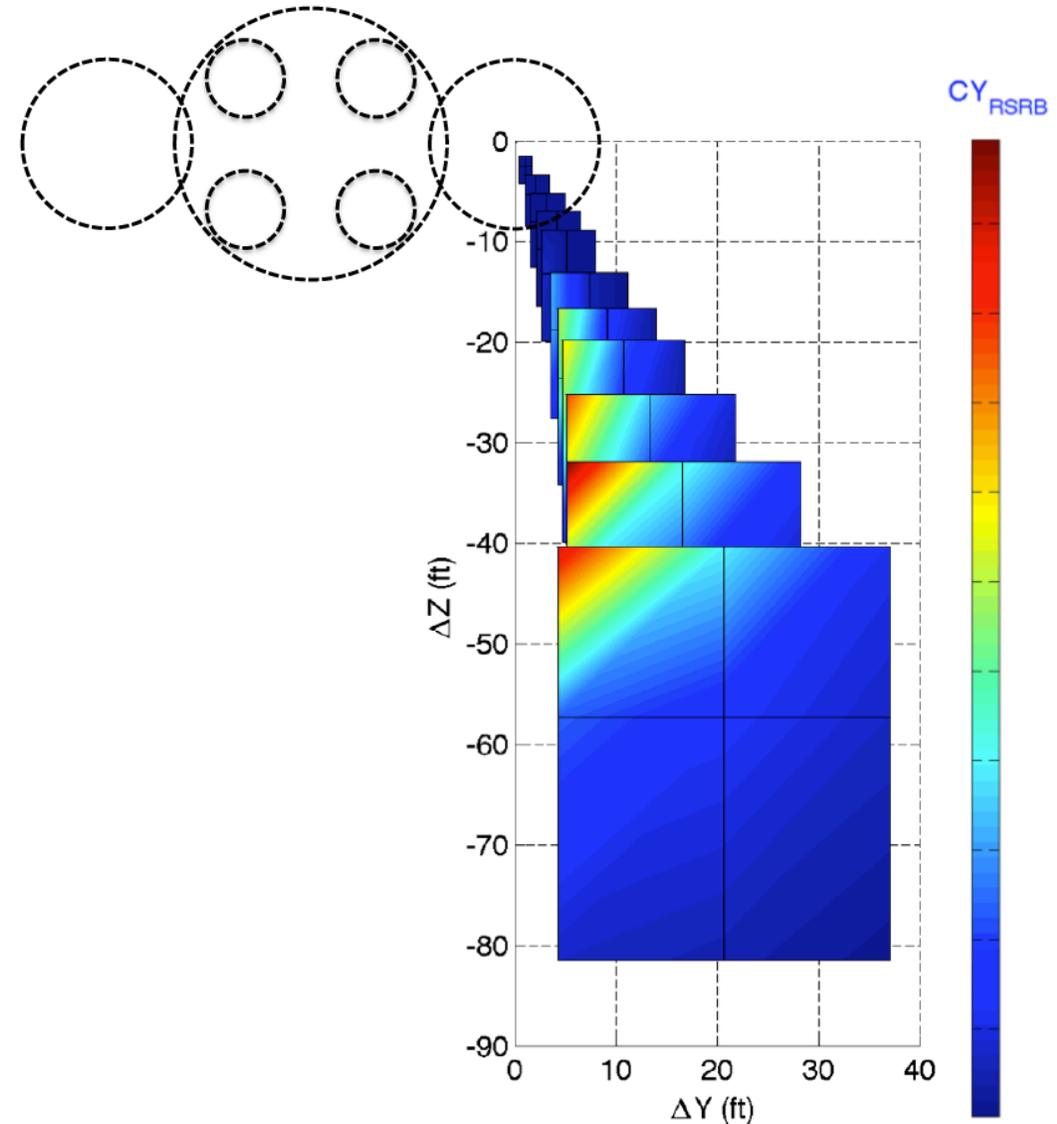
# RESPONSE SURFACE MODELING (CONT.)

- **Higher degrees of freedom**

- Examples
  - Booster separation (AIAA Paper 2016-0798)
  - **Liftoff and Transition Line Loads (More to follow)**
- Tools
  - Kriging
  - **Reduced order modeling**
  - **Data fusion**
- Advantages
  - Able to model complex systems
    - Multiple inputs and multiple outputs
- Weaknesses
  - Modeling can be time consuming
    - Often necessary to breakup complex database into sections
  - Large overhead by research team to verify models
    - Difficult to visualize and interpret multidimensional databases

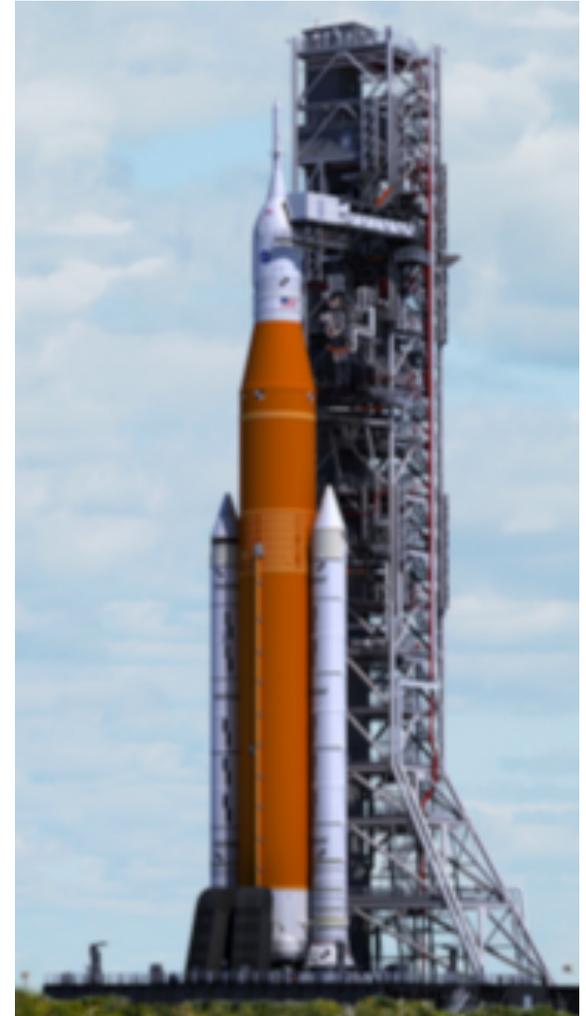
- **Under consideration and development**

- Cokriging for multi-fidelity data fusion
- Machine learning with neural networks
  - Simple neural network architectures show promise for booster separation databases

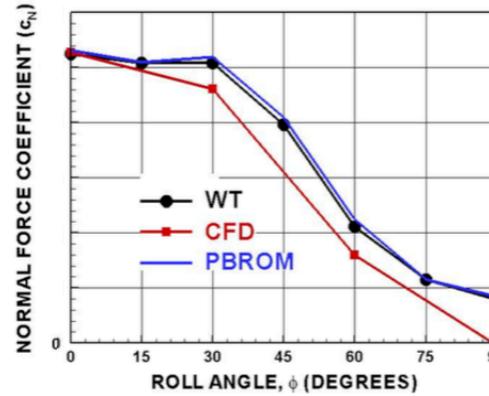
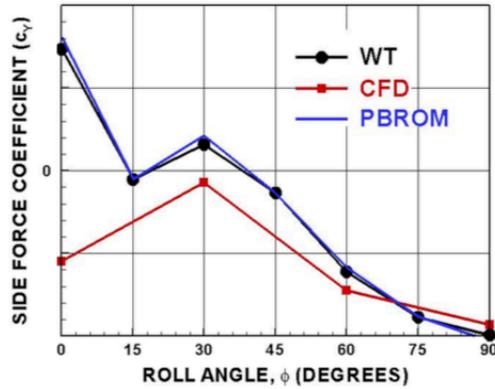
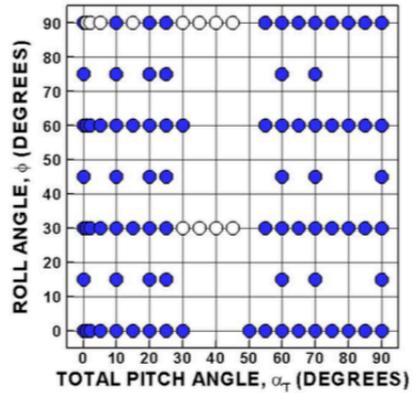


# DATA FUSION REDUCED ORDER MODELS

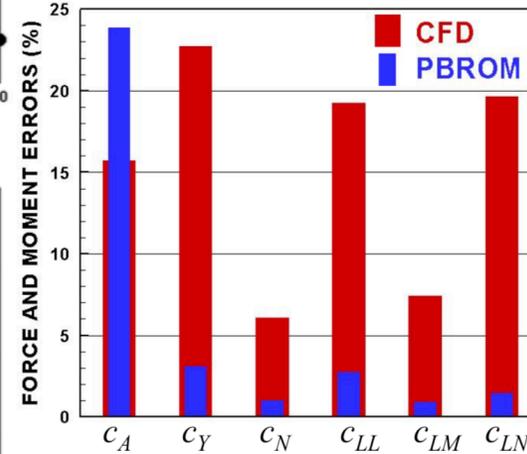
- **Pre-launch and Liftoff conditions represent some of the most challenging environments to predict for a launch vehicle, both experimentally and computationally.**
- **Reduced Order Modeling (ROM) was utilized to develop the SLS block 1 liftoff and transition force and moment database because of the high operational density and accuracy of the wind tunnel data and the high spatial density of the CFD. The Physics-based ROM methodology consisted in:**
  - 1. Spatially interpolate 21 RANS/DES CFD solutions onto a common grid (RANS grid)**
  - 2. Assimilate CFD data and Wind Tunnel (WT) surface pressure data at 95 conditions**
  - 3. Compute POD modes and project onto surface data to obtain POD coefficients**
  - 4. Assimilate WT force and moment data: adjust POD coefficients, using all WT data (pressures, forces, and moments)**



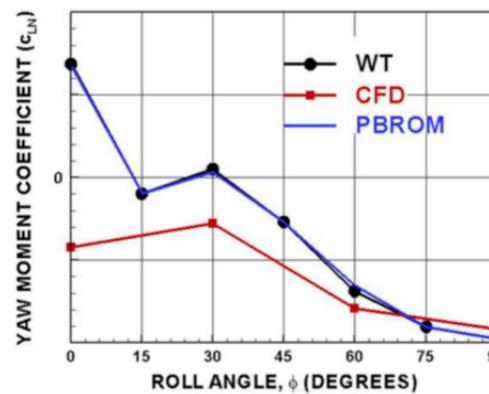
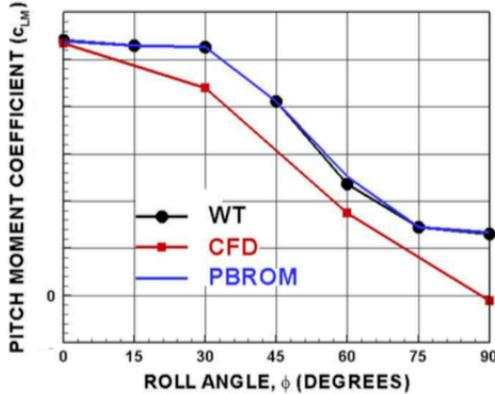
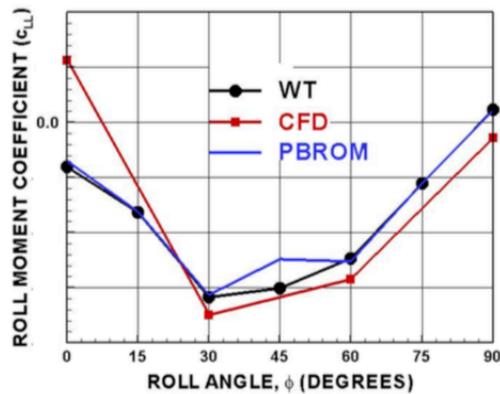
## Forces and Moments ( $\alpha_T = 30^\circ$ )



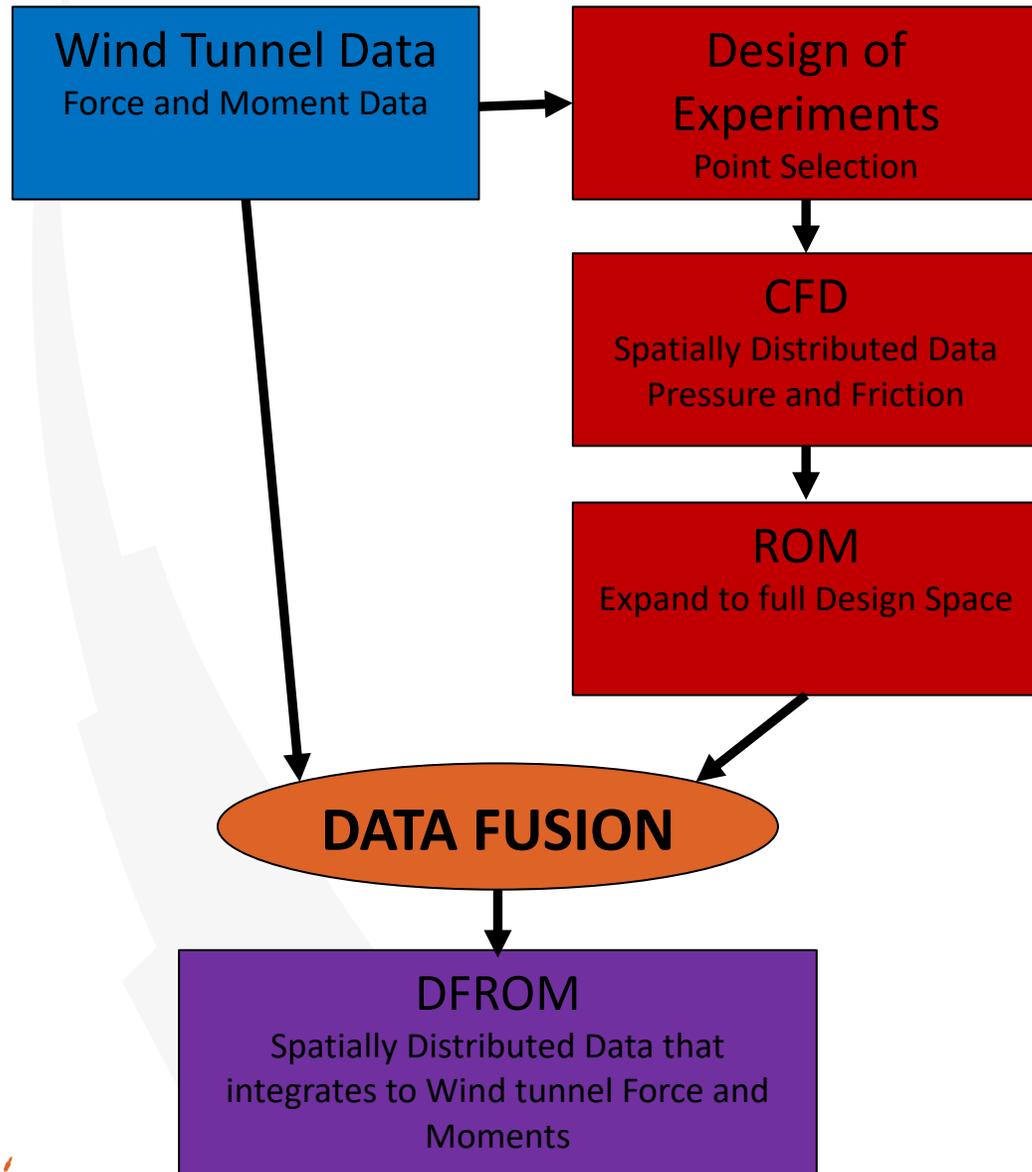
## Force and Moment Errors



- Averages of absolute errors normalized by root mean square values of wind tunnel forces and moments
- Covers only conditions for which there are CFD solutions ( $N = 21$ )



# DATA FUSION REDUCED ORDER MODELS

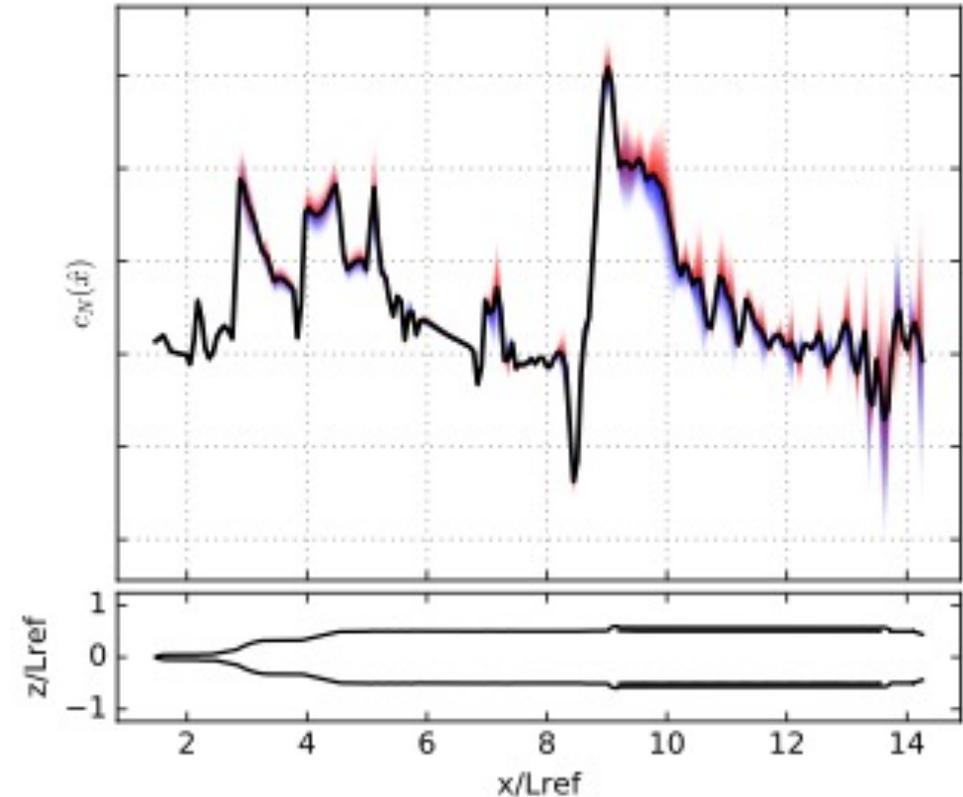


- **Liftoff and Transition Databases**
  - Distributed force database
    - Requires computational work
  - Computationally difficult regime
- **Take advantage of wind tunnel data**
  - Optimize point selection
  - Source of trusted data
- **Reduced Ordered Model**
  - PCA/POD methods
  - Reduce number of points needed
- **Data Fusion**
  - More robust solutions
  - Make up for CFD shortcomings

AIAA 2018-3640 and AIAA 2019-3401

# FUTURE DATA FUSION REDUCED ORDER MODELS

- **Expand for multiple fidelity CFD sources**
  - Focuses limited computational resources to where they are needed most
- **Expand to DFROM to near body volume**
  - Allow NS equation-based constraints
  - Allow for greater qualitative checks on model outputs
- **Design UQ into model generation**
  - Leverage Machine Learning techniques to carry uncertainty throughout the analysis
  - Allow for tighter tolerances
- **Take Advantage of API style databases**
  - Allow for UQ complexity to match nominal model



Dispersed  $C_N$  from AIAA 2018-3640

AIAA 2018-3640 and AIAA 2019-3401

# PUBLICATIONS

- **H. A. Carlson, R. Verberg, J. T. Pinier, and S. E. Krist. Reduced-Order Model for NASA's Space Launch System Liftoff Aerodynamics, 53rd AIAA Aerospace Sciences Meeting. American Institute of Aeronautics and Astronautics, AIAA 2015-0777, 2015.**
- **J. T. Pinier, A. J. Herron, and R. J. Gomez. Advances in the Characterization of NASA's Space Launch System Aerodynamic Environments, AIAA Aviation Forum, AIAA 2019-3397, 2019.**
- **P. R. Shea, J. T. Pinier, H. P. Houlden, A. L. Favaregh, M. J. Hemsch, D. J. Dalle, S. E. Rogers, J. G. Meeroff, and H. C. Lee. Ascent Aerodynamic Force and Moment Database Development for the Space Launch System, AIAA Aviation Forum, AIAA 2019-3298, 2019.**
- **T.J. Wignall. Data-fused Reduced Order Model Development for Launch Vehicle Aerodynamics, AIAA Aviation Forum, AIAA 2019-3401, 2019.**
- **D. J. Dalle, S. E. Rogers, H. C. Lee, and J. Meeroff. Adjustments and Uncertainty Quantification for SLS Aerodynamic Sectional Loads. AIAA Applied Aerodynamics Conference. American Institute of Aeronautics and Astronautics, 2018.**

# POINTS OF CONTACT

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