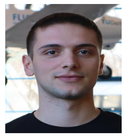
Stall Dynamics and Sensitivities on HL-CRM

Juanita Osorio Tovar
MSc student



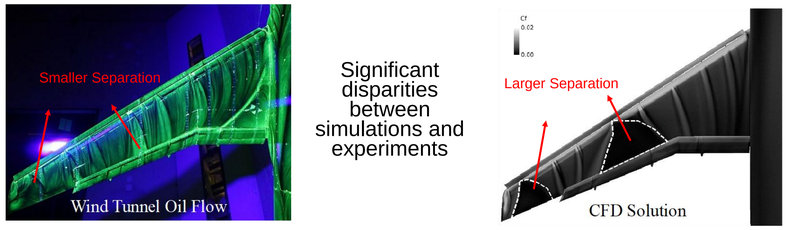
Alessandro Pulimeno
PhD student

Kevin Manohar
PhD student

Dr. Owen Williams
Associate Research Professor

Turbulent flow separation prediction limits designs and adds cost

Predicting flow behavior and performance at the edges of the flight envelope remains a significant challenged due presence of large unsteady and three-dimensional separated regions.



Comparison of oil flow visualization and equivalent CFD simulation on HL-CRM model [1]

"Critical need for a vastly improved computational capability for high-lift airplane design, system development, and product certification"… by acquiring more wind tunnel data

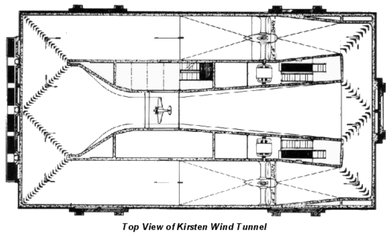
- Slotnick & Mavriplis (2021)

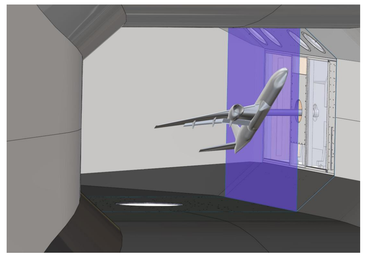
Our role

- Close integration with the CRM ecosystem, of which Boeing is a leader, and designed the HL configuration.
- **Focus**:
  - Sensitivities of slat bracket wakes and flap separation, identified as areas of great uncertainty and modeling challenge by the HLPW series.
  - Unsteady dynamics are key to insights into separation features. We focus on critical unsteady measurement capabilities (PIV, unsteady pressures, unsteady TSP for surface topological evolution and streamlines).
  - Leverage data-driven modeling expertise at UW focusing on augmentation of experimental data (temporal super-resolution and extraction of unmeasured variables).

Leveraging the Kirsten Wind Tunnel to test 4% CRM-HL test

Tests will be conducted in the 8 x 12 ft Kirsten Wind Tunnel (KWT) at the University of Washington on a half-span HL-CRM model.



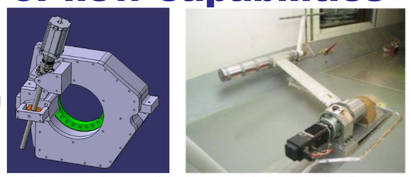


Left: KWT top view [3]. Right: CRM model with splitter plate integration.

Phase 1: Development of new capabilities

New tunnel hardware

Improvements to side wall balance to handle the large loads associated with high-lift configuration testing.
Quantitative wake survey system (QWSS) capstone in 2025



Left: KWT side wall balance. Right: QWSS in KWT

Scanning of as-built tunnel geometry and re-qualification of KWT flow

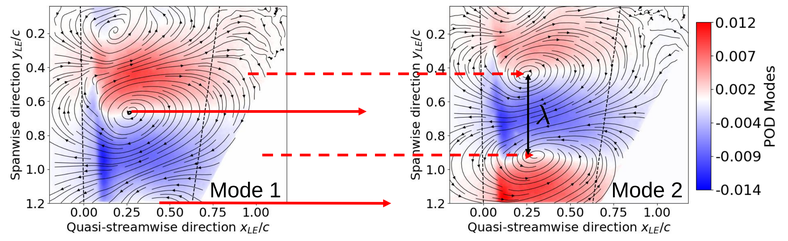
Measurement of tunnel geometry, turbulence and uniformity to aid validation of simulation tools

KWT scan as seen by the scanning software.

HS-CRM in KWT during PIV testing

Deployment of quantitative off-body particle image velocimetry in the KWT for the first time

Proof of PIV data on side-wall balance calibration model. Identified spanwise travelling mode similar to stall cells

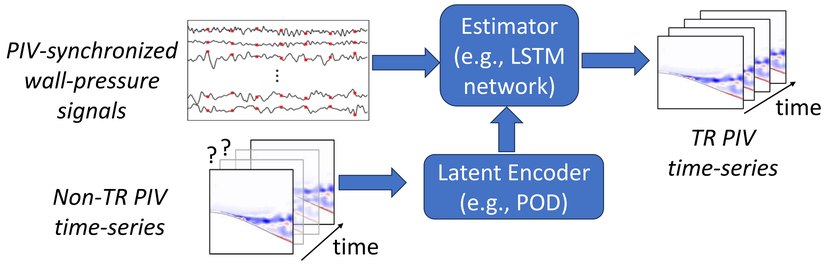


Most energetic POD modes of top-down PIV data, representing a mode pair shifted by half the spanwise length scale.

Data-driven Reconstruction of Sparse Measurements

Temporal Super-Resolution

- 2D2C PIV data is non-time-resolved (TR), under-sampling unsteady separation dynamics, which can lead to aliasing
- Our approach is to use sparsely-placed *unsteady wall-pressure sensors* to estimate the TR evolution of 2D2C PIV flow-field using an LSTM neural network [2]



Inference of Unmeasured Variables

- Current development of physics-constrained models to infer *out-of-plane velocity* and *pressure* flow-field from 2D2C PIV
- Volumetric 3D3C reconstruction from multiple 2D2C PIV planes

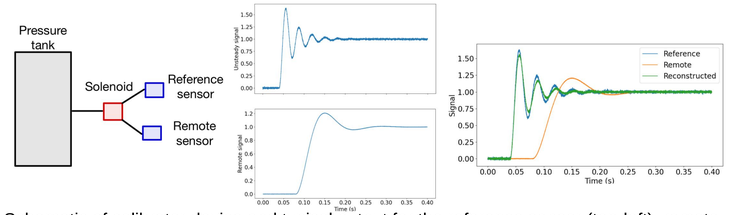
Toward unsteady pressure measurement on conventional wind tunnel models by compensating for tubing

Unsteady pressure:

- Flush-mounted sensors are impractical on 100+ pressure taps.
- Conventional pressure tubes attenuate the signal, losing transient behaviors and resulting in averaged outputs.

Our approach:

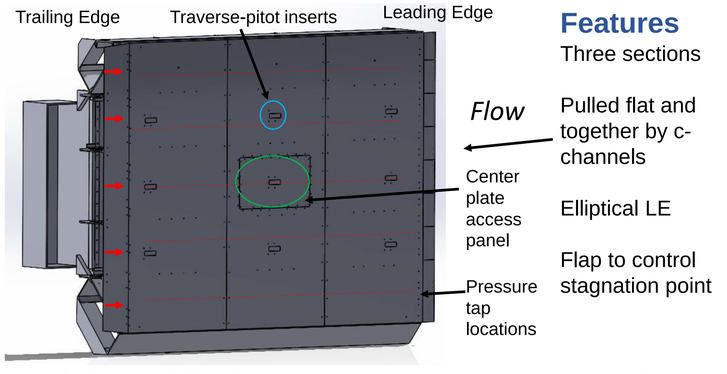
- Employ tubing compensation technique (Wiener Deconvolution) to reconstruct the unsteady signal.



Schematic of calibrator device and typical output for the reference sensor (top-left); remote sensor (bottom-left); compensation algorithm (right).

Why use a Splitter Plate?

- Continuous wind tunnels have very thick and non-canonical boundary layers that will alter half-model loads
- KWT's test section has chamfers which limit max AOA.
- Solution is a splitter plate with controlled BL



Splitter plate CAD design, mounted onto the tunnel's test section west wall.

Upcoming Phase 2: Leverage new capabilities to explore high-lift configuration sensitivities and improve design tools

Combine 2D3C (Stereo)PIV with unsteady surface pressure measurements to create simultaneous estimation in 3D flow [2].

2025 Splitter plate qualification testing and completion of tunnel preparatory work

Late 2025-Early 2026: Testing of relevant high-lift models in KWT

References

[1] Ito et al., HLPW-3, 2017.
[2] Manohar et al., Exp Fluids, 2023.
[3] KWT Technical Guide