National Aeronautics and
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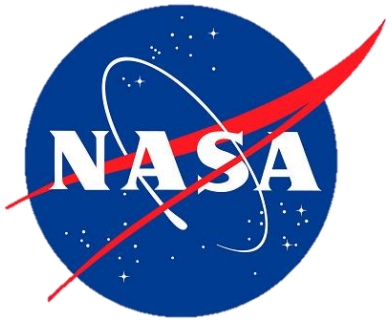

X-57 “Maxwell” High-Lift Propeller Test for Improved Thrust Measurements and Slipstream Velocities

2022 AIAA Aviation Forum: ACD-10/EAT-02/TF-12

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Tuesday, June 28, 2022

Introduction

- NASA's X-57 "Maxwell" concept uses distributed electric propulsion technology that includes 12 high-lift propellers (HLPs).
- The HLPs are designed to augment lift at low speeds, and are otherwise turned off and passively fold against nacelles in cruise flight.
- The HLPs enable increased aerodynamic efficiency in the cruise configuration by allowing for a much more highly-loaded wing without sacrificing low-speed capabilities.
- The HLPs have been extensively analyzed, and full-scale prototypes have been tested at NASA Langley's Low Speed Aeroacoustic Wind Tunnel (LSAWT) in 2020 and 2022.

X-57 Mod IV in Low-Speed (Takeoff/Landing) Configuration

X-57 Mod IV in High-Speed (Cruise) Configuration

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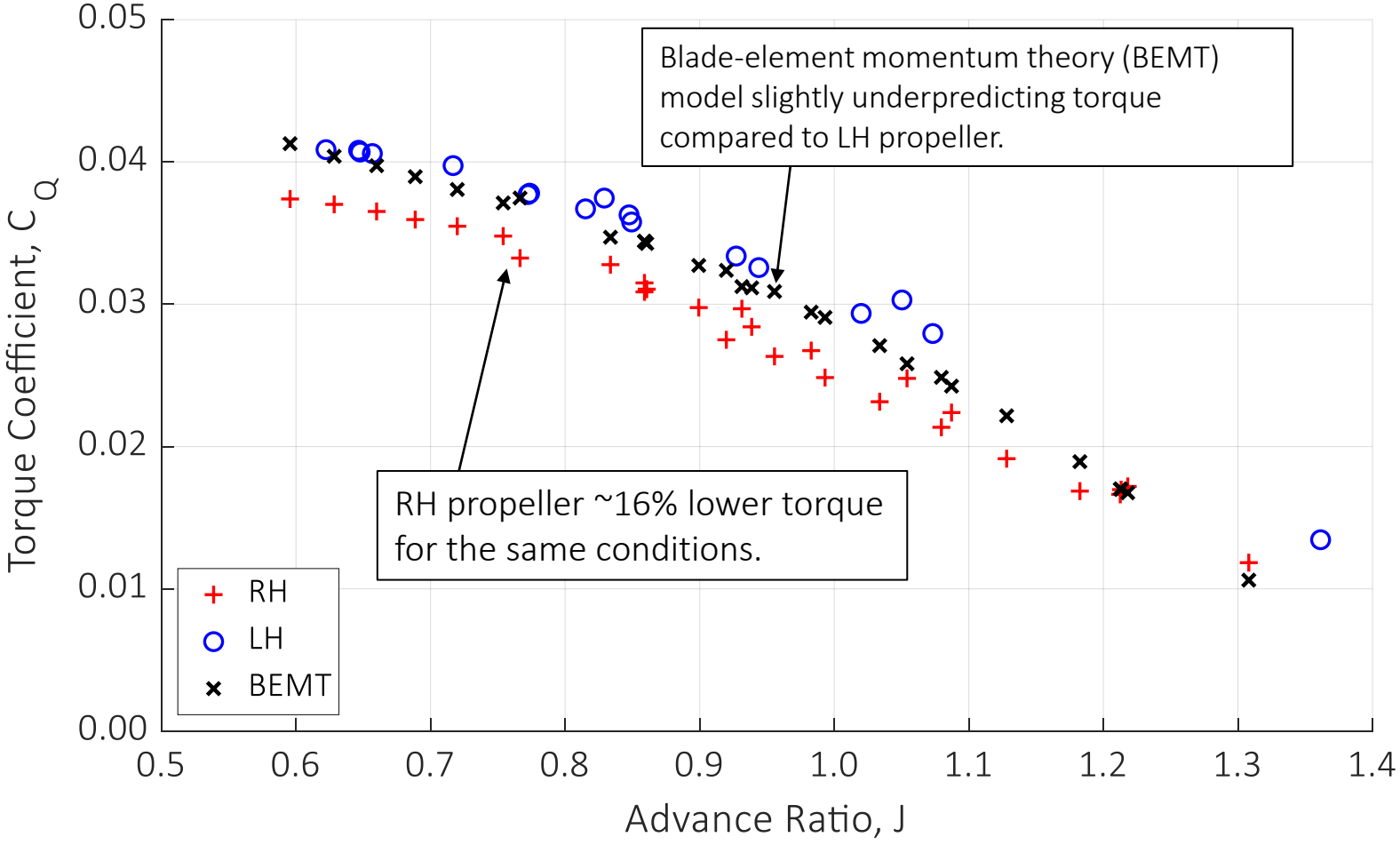
Prior High-Lift Propeller Test Results

- First Propeller Test Stand (PTS) evaluation of the full-scale HLPs occurred in late 2020.
- Right-hand (RH) prop showed reduced performance compared to the left-hand (LH) prop.
- RH blades ~5% lower weight than LH blades. RH blades may partially unload at higher RPM.



Paper
https://ntrs.nasa.gov/citations/20210016834
Presentation:
https://ntrs.nasa.gov/citations/20210017259

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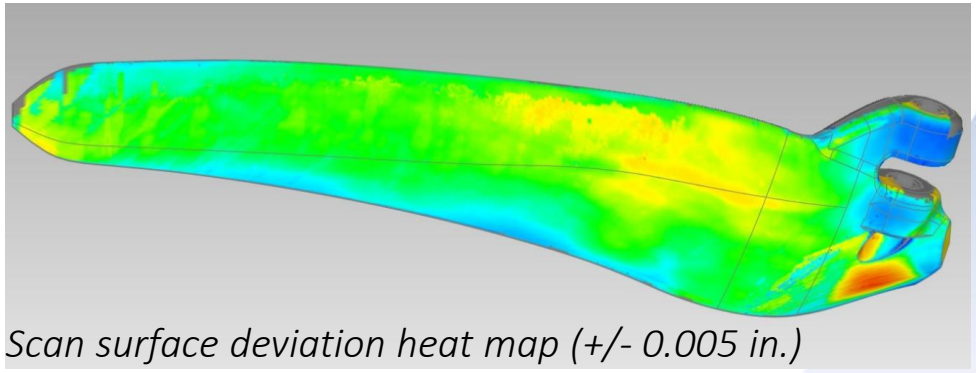
Intermediate Testing & Tolerance Improvements

- Suspected RH propeller of diminished material properties and stiffness. Investigated with:
  - close examination and processing of high-speed video imagery,
  - laser surface scans of RH and LH propeller blades to compare to CAD models,
  - calibrated weight bend test of RH and LH propeller blades (5 lb and 10 lb weights),
  - and propeller coning angle comparisons to CAD dynamics simulations.
- Proposed testing new propellers manufactured with much tighter weight tolerances.
  - Heaviest to lightest propeller blade set may vary no more than 0.025 oz.
  - Contractor manufacturing practices resulted in much less variation among blades.
- Blades are designed to produce uniform axial velocity.
  - Conduct propeller wake survey in addition to performance test.
  - https://ntrs.nasa.gov/citations/20160007767

HLP bend test

Digital multiple exposure of high-speed imagery



Scan surface deviation heat map (+/- 0.005 in.)

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X-57 Maxwell High-Lift Propeller Test Setup

Low-Speed Aeroacoustic Wind Tunnel (LSAWT)
Test Section

Mic Array

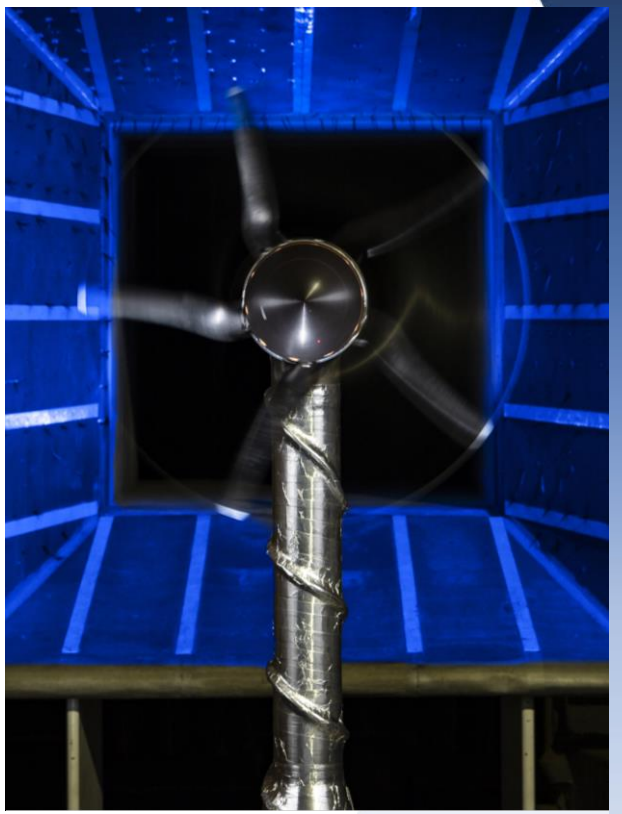
PTS

HLP Assy

Acoustic Wedges

Pitot Probe

Inlet Nozzle



Downstream view of deployed HLP

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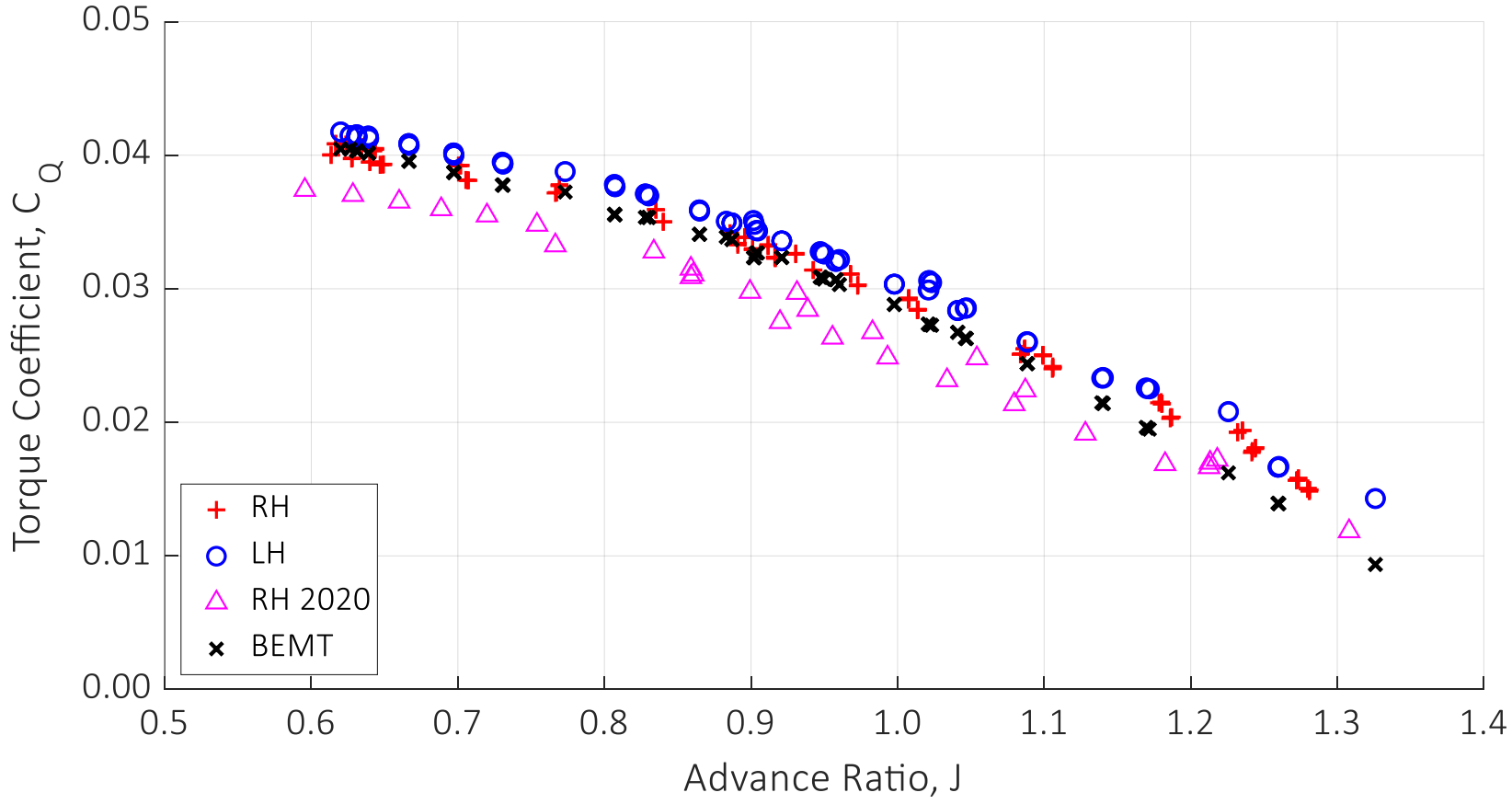
X-57 Maxwell High-Lift Propeller Test Results

- Torque measurements were very steady and repeatable as in prior test.
  - New propellers show very similar torque over the operating range.
  - 2020 RH propeller torque well below predicted values.
- BEMT model is very slightly underpredicting torque, as expected.



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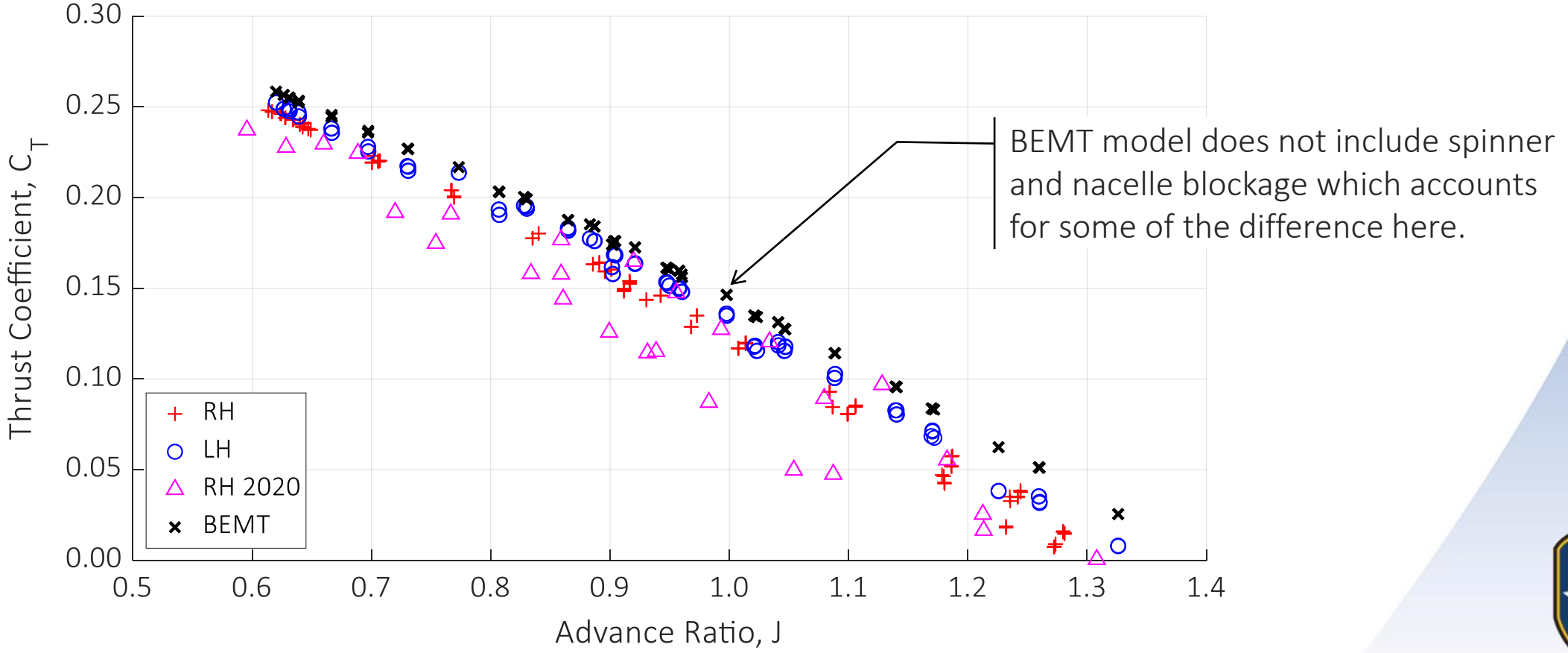
Test Results (contd.)

- Thrust measurement quality significantly improved over 2020 test.
  - Much tighter grouping and repeatability of new measurements.
  - New propellers show very similar thrust performance.
- BEMT model slightly overpredicting thrust, as expected.



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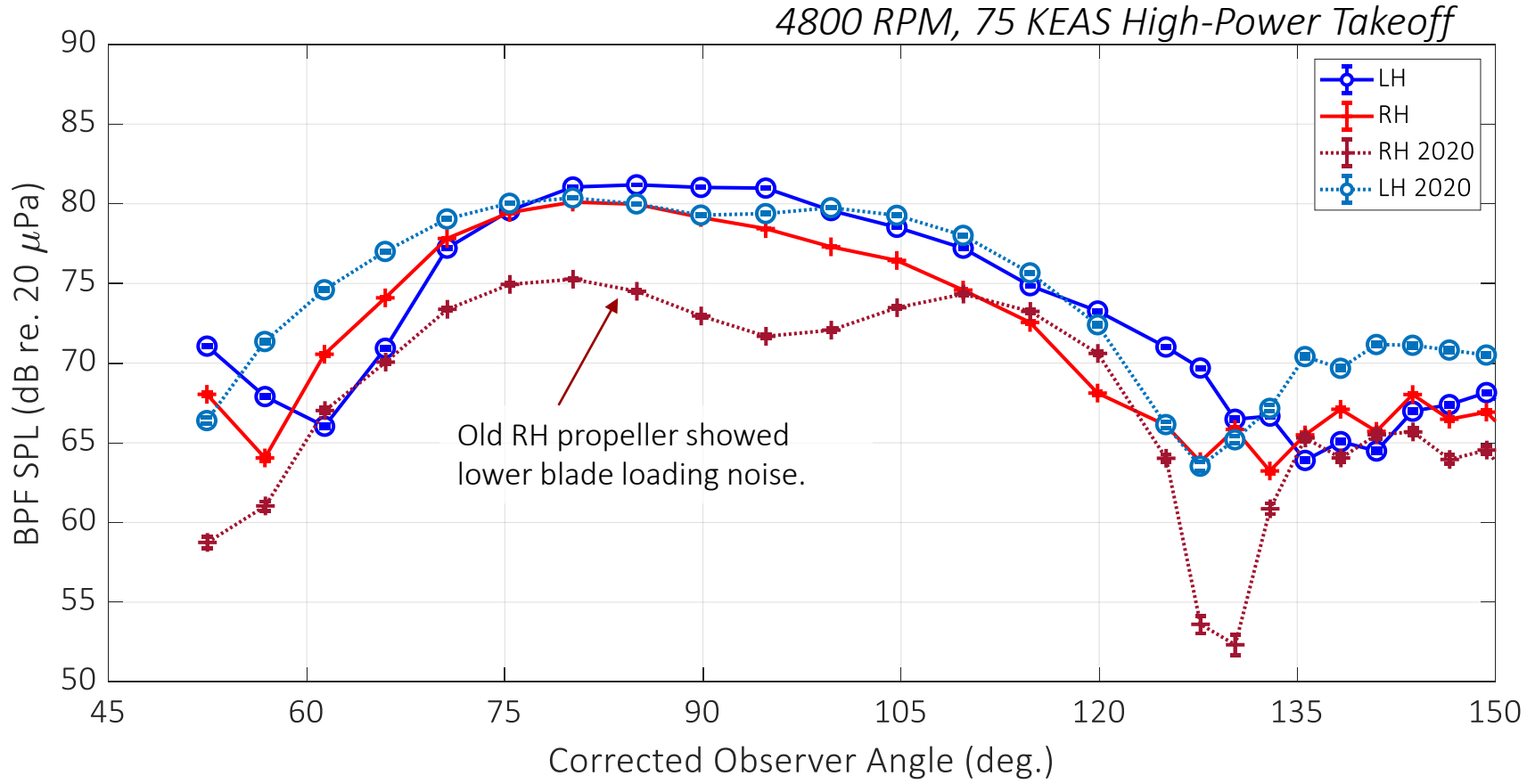
Test Results (contd.)

- New propellers produce very similar noise compared to 2020 LH propeller.
- RH propeller from 2020 exhibits lower fundamental acoustic levels.
  - Corroborated by lower torque levels and predictions revealing HLP to be dominated by aerodynamic loading noise.



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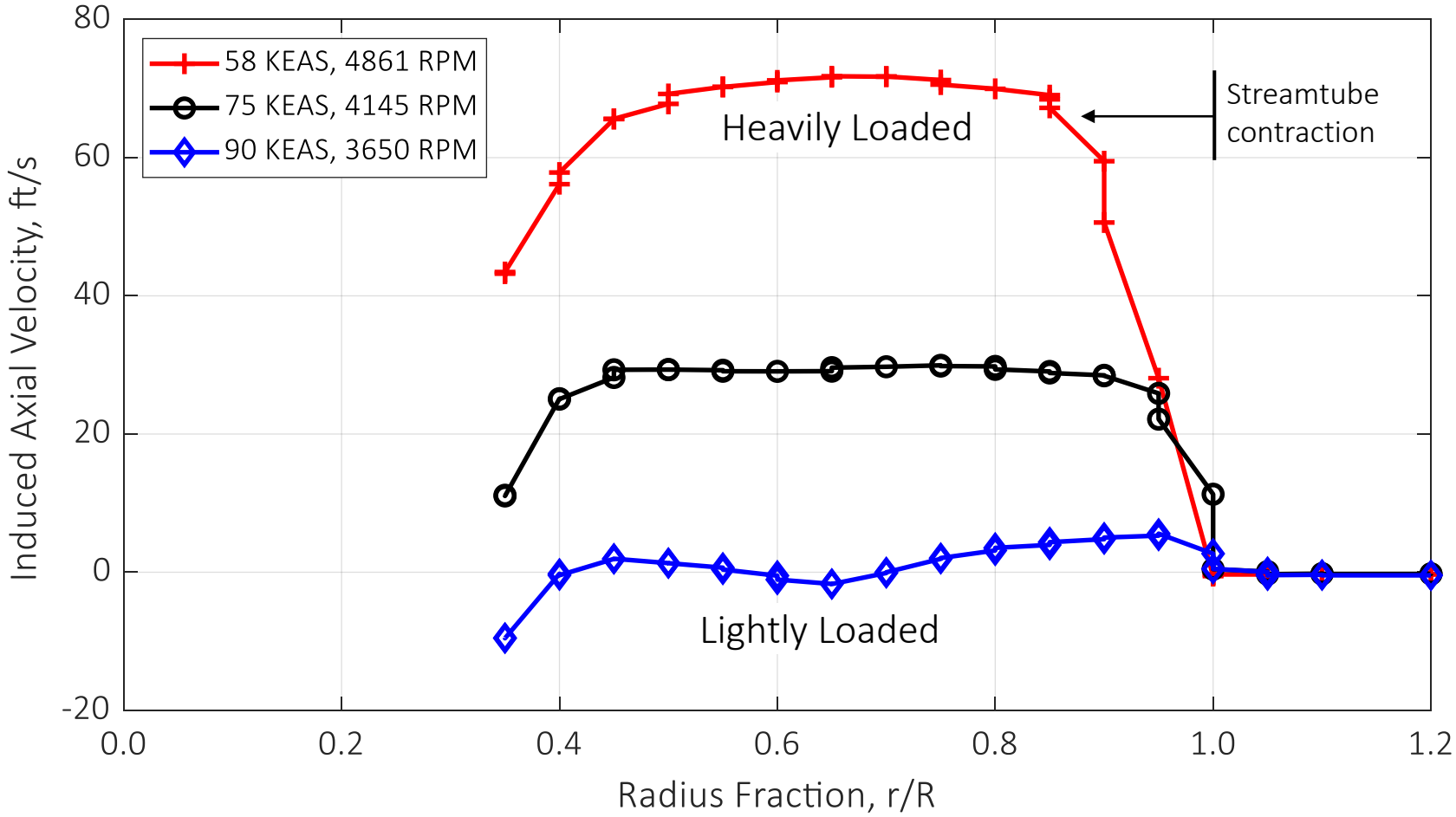
Test Results (contd.)

- Propeller induced velocities were relatively uniform at multiple freestream speeds.
  - Stronger tip vortex with higher blade loading results in additional tip losses.
  - Repeated point data spread is larger within the tip vortices.



Induced axial velocities one propeller radius aft of the center of rotation.

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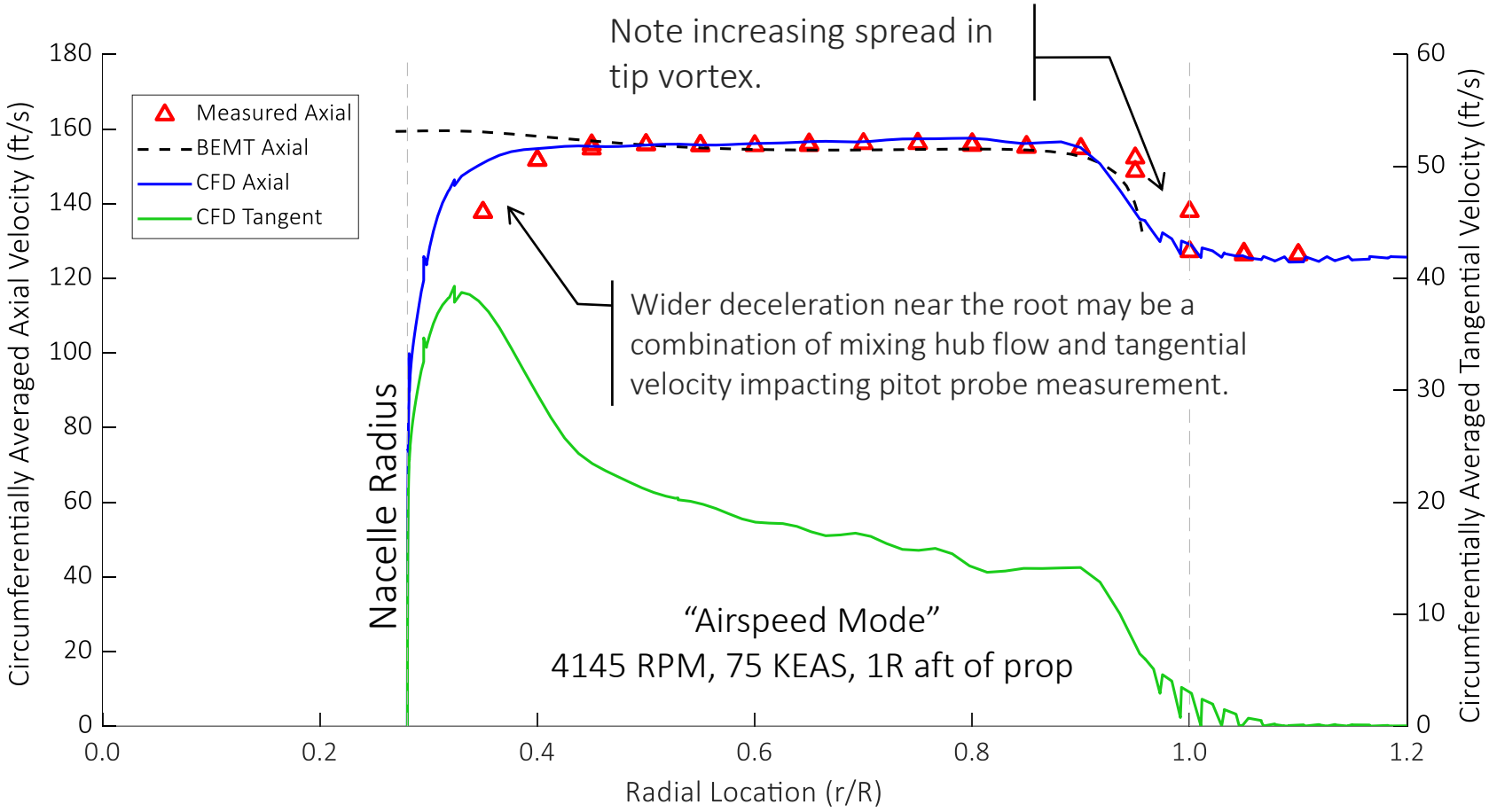
Test Results (contd.)

- OVERFLOW CFD simulations capturing wake velocities well. https://overflow.larc.nasa.gov/
  - BEMT model is predicting wake profile but needs correction for nacelle losses at the root.
  - BEMT model accuracy improves confidence in performance estimates for mission planning.



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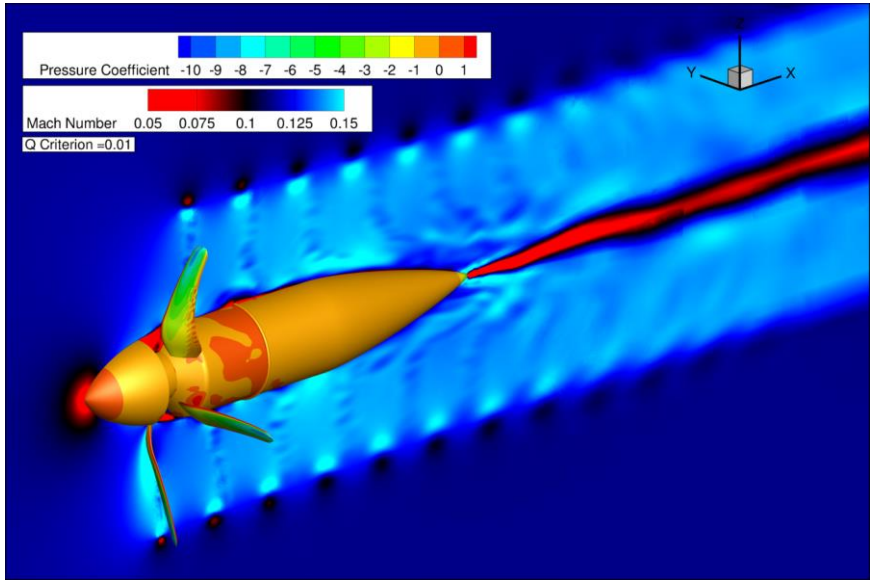
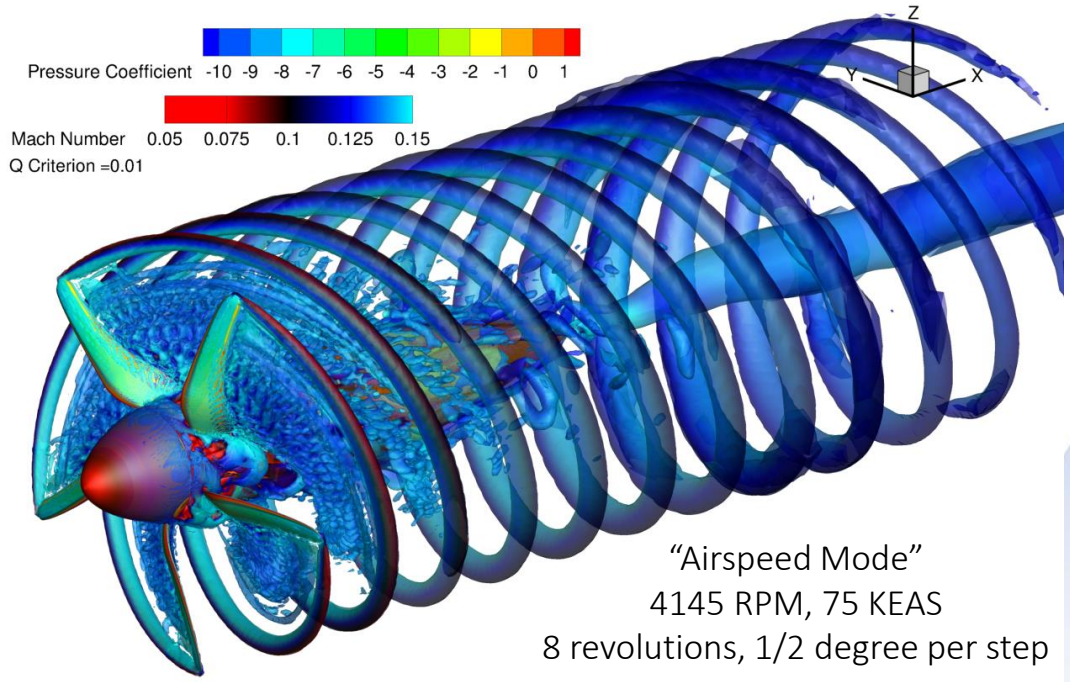
X-57 HLP Test Impacts & Future Work

- Provided significant benefit to X-57 Maxwell and advanced aircraft studies.
  - Verified balanced performance of flight-like propellers built with new manufacturing tolerances.
    - Measured wake velocities meet or exceed predictions for lift augmentation.
  - HLP BEMT model predicted propeller performance well.
  - New OVERFLOW methods improved predictions compared to prior simulations. Useful for wing-integrated propulsion cases.
  - Wake survey provides a valuable data set for tool validation studies.
  - Acoustic data verify performance and highlight value of multiple measurement types.
- Knowledge transfer to public, other Agencies, and industry partners.
  - Upcoming detailed NASA Technical Memorandum.
  - X-57 Technical Publications Page
    https://www.nasa.gov/aeroresearch/X-57/technical/index.html





"Airspeed Mode"
4145 RPM, 75 KEAS
8 revolutions, 1/2 degree per step

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Acknowledgments

NASA's Aeronautics Research Mission Directorate

Transformational Aeronautics Concepts Program

– Convergent Aeronautics Solutions Project –

– Transformational Tools and Technologies Project –

Integrated Aviation Systems Program

– Flight Demonstrations and Capabilities Project –

– – X-57 Maxwell Subproject – –

Advanced Air Vehicle Program

– Revolutionary Vertical Lift Technology Project –

High-Lift Propeller CAD/Fabrication

– Empirical Systems Aerospace, Inc. –

Propeller Test Stand Design/Build

– ViGYAN, Inc. –

We would also like to express our gratitude to the LaRC LSAWT team for their dedication and expertise which made this such a successful test.

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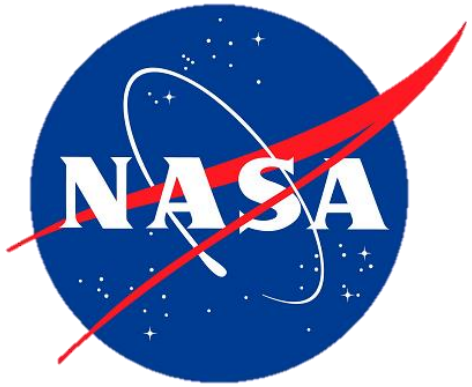

Thank you!
Questions?