Oral presentation | Multi-phase flow
High performance computing-II
Wed. Jul 17, 2024 10:45 AM - 12:15 PM Room D

[7-D-02] 10 Years of AIAA Hover Prediction Workshops: State-of-the-Art and Future Plans

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Keywords: Rotorcraft hover, High fidelity simulations, HVAB rotor

Applied Aerodynamics
Technical Committee

https://www.aiaa-hpw.org/

10 Years of AIAA Hover Prediction Workshops (HPW): State-of-the-Art and Future Plans

Dr. Nathan Hariharan
Chair, AIAA Hover Prediction Workshop
Chief Technologist, HPCMP CREATE

ICCFD 2024, July 17, Kobe, Japan

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Dr. Bob Narducci
The Boeing Company: Technical Fellow

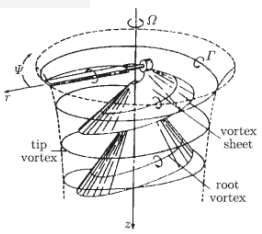
Dr. Brian Wake
Sikorsky Aircraft - A Lockheed-Martin Company: LM Fellow

The Hover Problem

Simulation of self-induced flow fields in near-zero winds to accurately predict rotor performance, loads, download, and acoustic signature of rotorcraft

Role of Vorticity in Fixed and Rotary Wings

- Vortex and vorticity are central to aerodynamic lift and lifting efficiency
- Trailing Vortices behind a jet-liner on final: Hazardous to flights behind, but minimal influence on the aircraft itself
- In hover, rotorcraft vortical systems coil helically underneath – huge aerodynamic influence on the generating aircraft



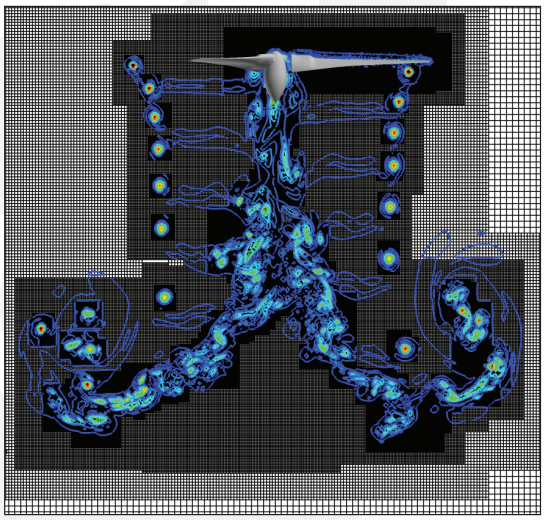
Why do we need a Hover Prediction Workshop (HPW)?

- Hover: True value of rotorcraft and is a limiting power design point
- Strong self-induced vortex system impact all aspects of hover
  - Accurate numerical predictions of efficiency require accurate modeling of the structure, strength and trajectory of the tip vortex.

Hariharan N., Egolf, T.A., Sankar, L.N., "Simulation of Rotor in Hover: Current State and Challenges," AIAA 2014-0041, National Harbor, MD, January 2014,

Why do we need a Hover Prediction Workshop (HPW)?

- A problem of computational scales:
  - Vortex core length scale is ~ 1/150 of a realistic rotor-blade span, and ~1/1500 of computational domain scales
  - Computationally Demanding
- Prediction precision required is demanding:
  - Even a difference of 0.01 (say 0.73 vs 0.72) in Hover Performance Efficiency prediction (Figure of Merit (FM)) is huge!
  - For a heavy vehicle the difference is ~200 lbs, 1 crew member

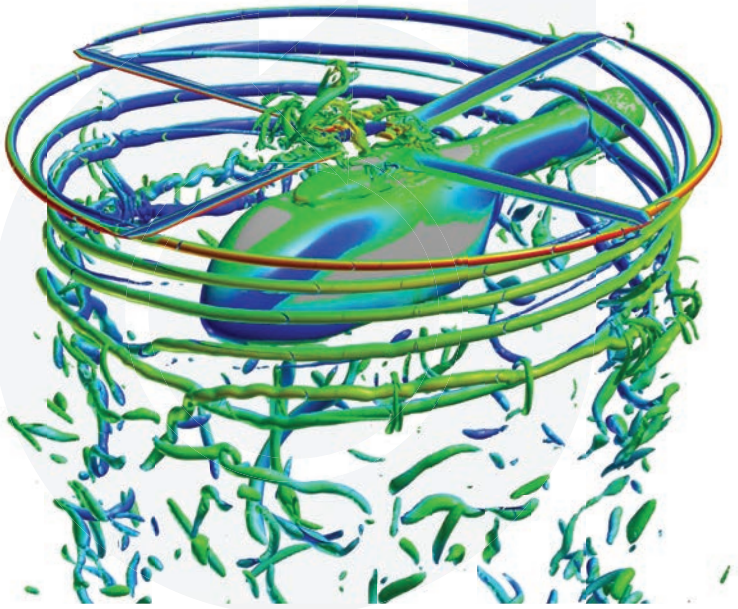


(Wissink, 2013, Helios)

Hariharan N., Egolf, T.A., Sankar, L.N., "Simulation of Rotor in Hover: Current State and Challenges," AIAA 2014-0041, National Harbor, MD, January 2014,

HPW Vision (2014)

Our vision is to inspire collaboration among industry, governments, and academia for the development of computational methods to predict all aspects of hovering flight efficiently, practically, and accurately



The idea of a workshop for hover came out of a lunch discussion at Aviation 2011 with Alan Egolf, Chief Aerodynamicist (now retired) at Sikorsky. Prof. Sankar of GaTech was also part of the initial triad.

10 Years Hence: HPW Headline Stats

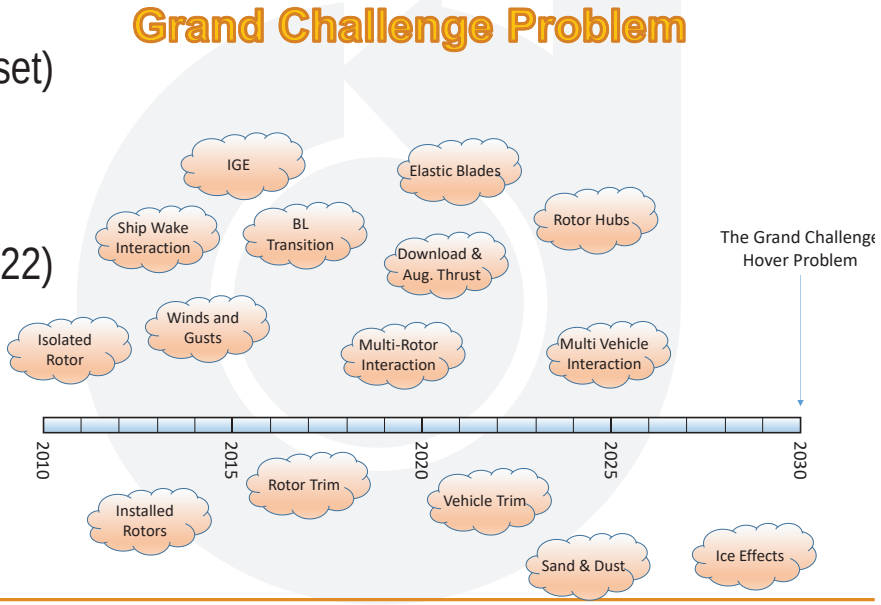
Since 2014*

- 100+ conference papers (13 industry, 39 university, 16 gov't, 26 mix)
- Over 100 different contributors
- 32 unique institutions (10 industry, 17 university, 5 gov't)
- 8 countries
- 3 common rotors (S-76, PSP, HVAB)

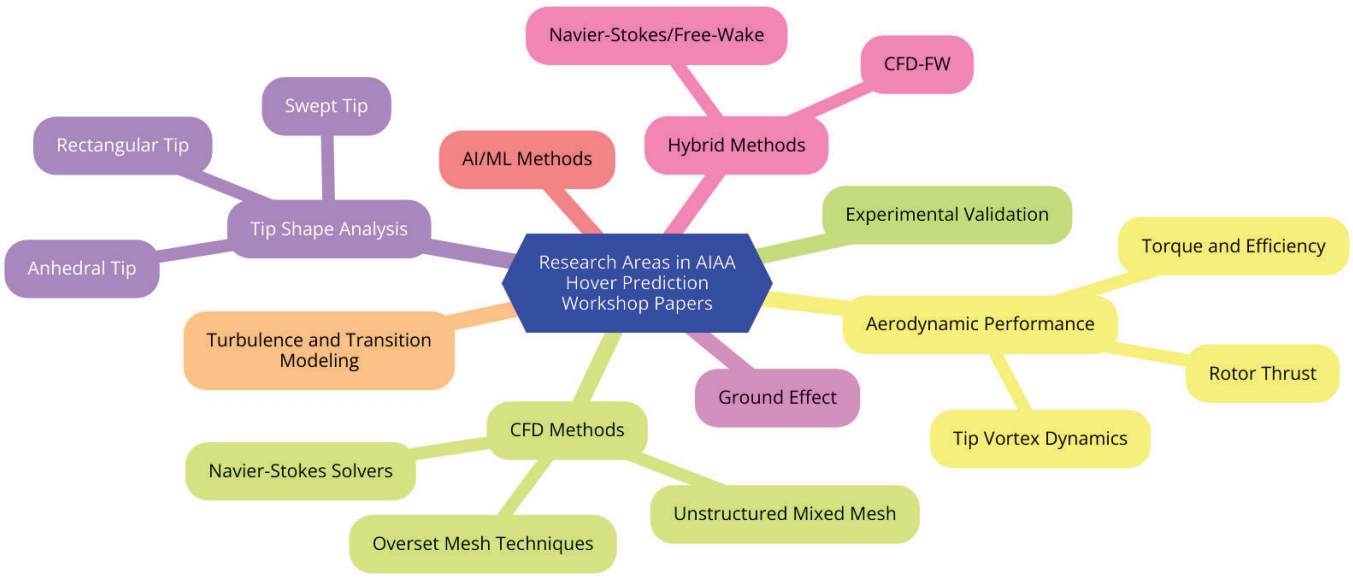
HPW Common Hover Problems

- Isolated Rotor: S-76 (2014) (old data set)
- Isolated Rotor: PSP (2018)
- Isolated Rotor: HVAB (2021)
- Full Aircraft: Hover Focus Problem(2022)

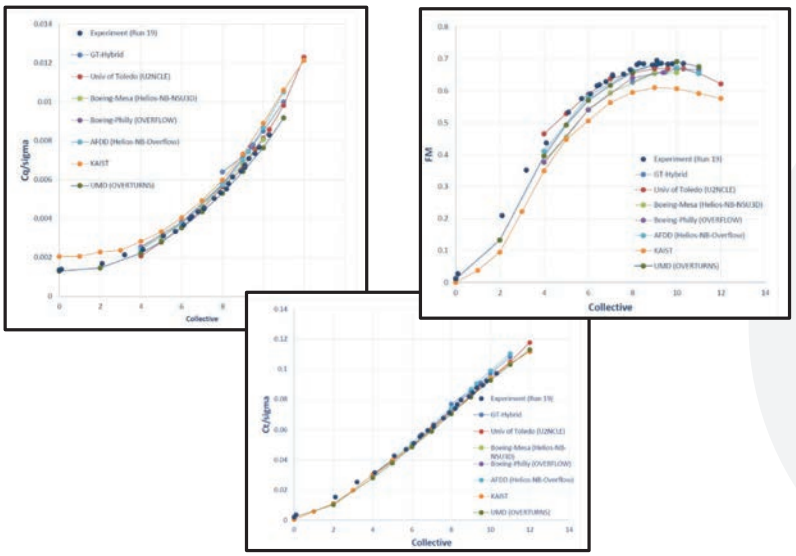
Geometry and surface grids are available on the website:
https://www.aiaa-hpw.org/
Google Keywords: HPW & AIAA



HPW Research Areas 2014-2024



HPW Focus Areas: (i) Integrated and Distributed Loads



Hariharan, N., Egolf, A., Narducci, R., and Sankar, L., SciTech 2015

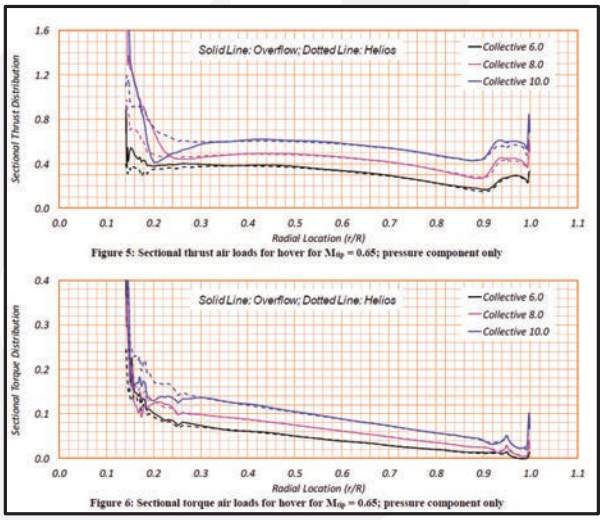


Figure 5: Sectional thrust air loads for hover for $M_{tip} = 0.65$; pressure component only

Figure 6: Sectional torque air loads for hover for $M_{tip} = 0.65$; pressure component only

Narducci, R., Jain, R., Abras, J., Hariharan, N., SciTech 2021

HPW Focus: (ii) Tip Shape Variation Analysis

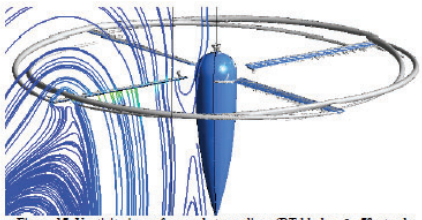


Figure 17. Vorticity isosurface and streamlines (RT blades, $\theta = 7°$, steady state solution, k-ω/SST, swirling strength = 0.005 s^{-1}, $C_T = 0.003729$, $C_Q = 0.00029$, $FM = 0.555141$)

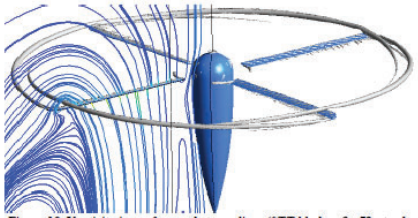
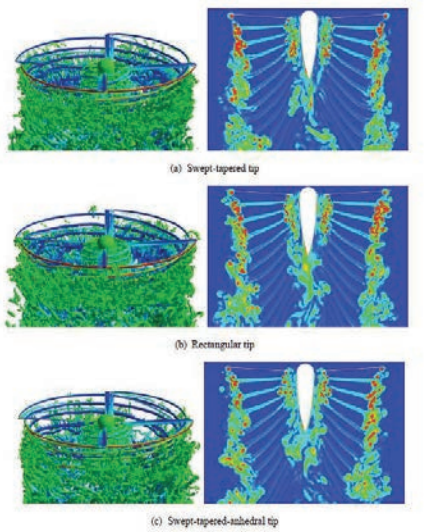


Figure 18. Vorticity isosurface and streamlines (STT blades, $\theta = 7°$, steady state solution, k-ω/SST, swirling strength = 0.005 s^{-1}, $C_T = 0.003966$, $C_Q = 0.000285$, $FM = 0.6197$)

Anusonti-Inthra, P., SciTech 2015

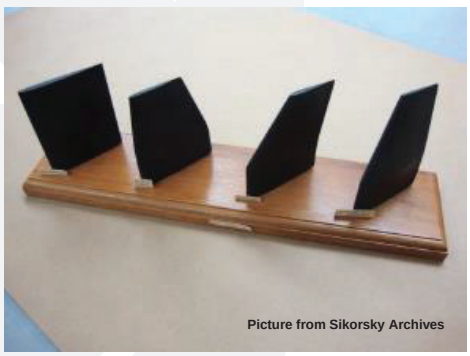


(a) Swept-tapered tip

(b) Rectangular tip

(c) Swept-tapered-anhedral tip

Jain, R., SciTech 2015



Picture from Sikorsky Archives

HPW Focus: (iii) Characterization of Aerodynamic Loads

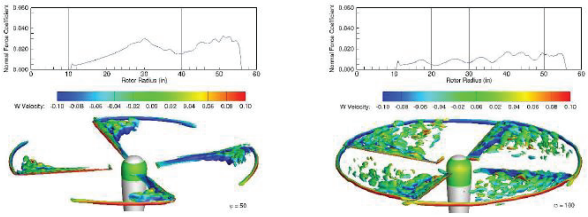
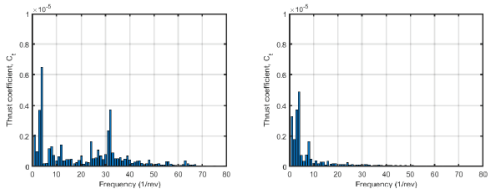


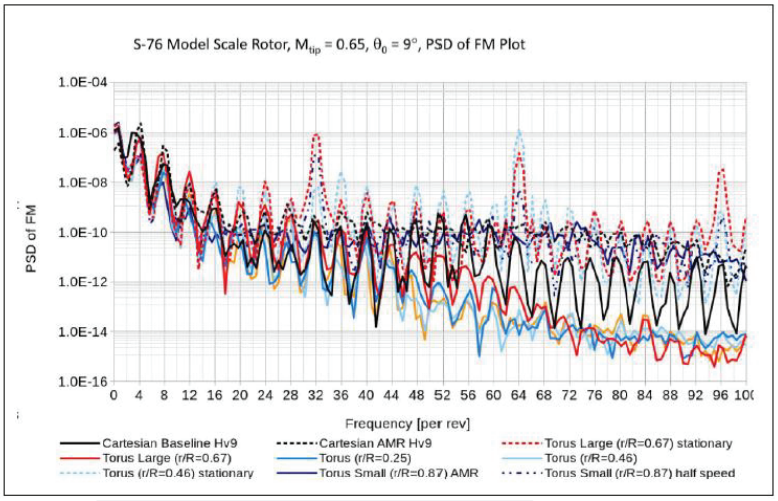
Fig. 24 Initial solution development through the first 100° of rotor rotation.

Abras, J., Narducci, R., and Hariharan, N., SciTech 2019



(c) Blended BDF with $\epsilon = 0.1$ (d) Blended BDF with $\epsilon = 1.0$ (BDF1)

Lee, B., and Baeder, J., SciTech 2021



Hariharan, N., Abras, J., and Narducci, R., SciTech 2020

HPW Focus: (iv) Rotor Variations

S76

Abras, J., Narducci, R., and Hariharan, N., SciTech 2021

PSP

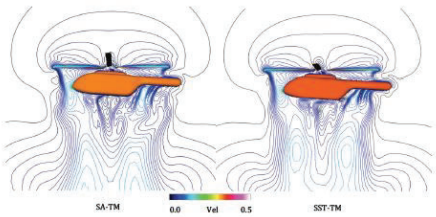


Figure 10 Total velocity contours predicted using SA and SST turbulence models

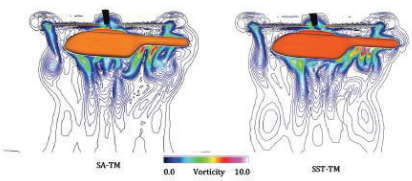
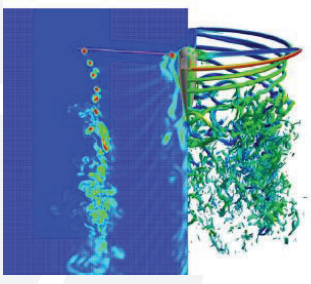


Figure 11 Vorticity contours predicted using SA and SST turbulence models

Zhao, Q., Baugher, S., and Sheng, C., SciTech 2019

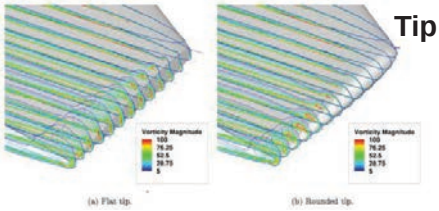
HVAB



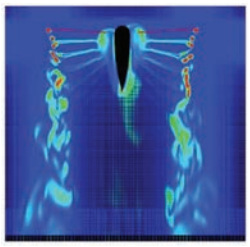
Narducci, R., Jain, R., Abras, J., Hariharan, N., SciTech 2021

HPW Focus: (v) Physical Parameter Studies

Tip Treatment

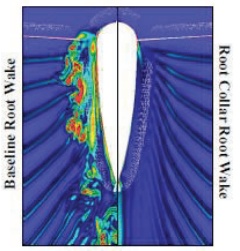


Garcia, A., and Barakos, G., SciTech 2015



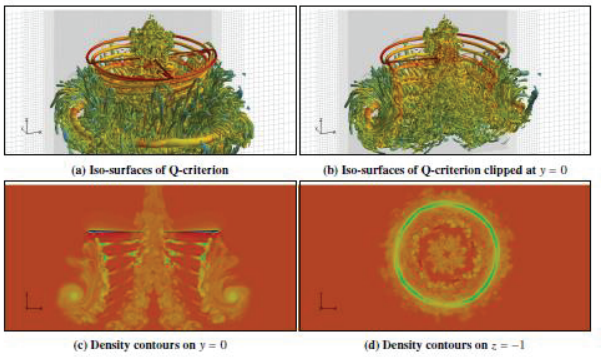
Narducci, R., SciTech 2015

Root Wake Impact



Abras, J., Narducci, R., and Hariharan, N., SciTech 2020

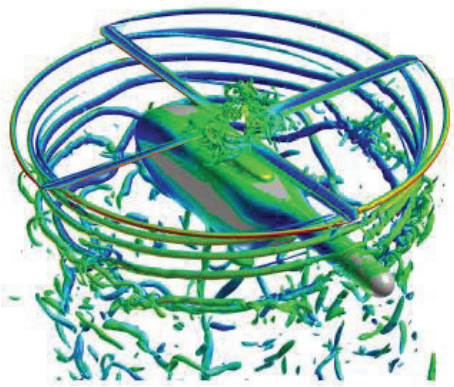
Grid Studies



Wood, S., Coder, J., and Hariharan, N., SciTech 2018

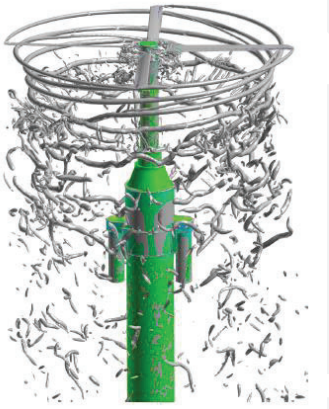
HPW Focus: (v) Physical Parameter Studies (contd)

Blade Elasticity

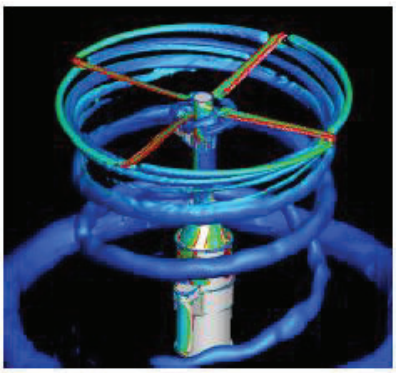


Jain, R., SciTech 2018

Test Stand Impact



Jain, R., SciTech 2018



Park, S., Han, J., and Kwon, O., SciTech 2021

HPW Focus: (v) Physical Parameter Studies (contd)

Fuselage Effects

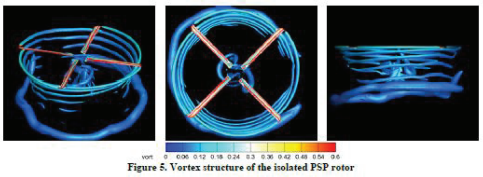


Figure 5. Vortex structure of the isolated PSP rotor

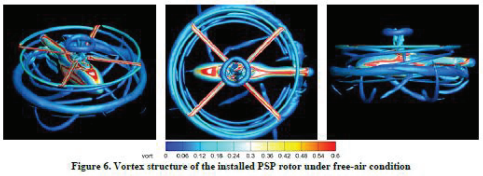


Figure 6. Vortex structure of the installed PSP rotor under free-air condition

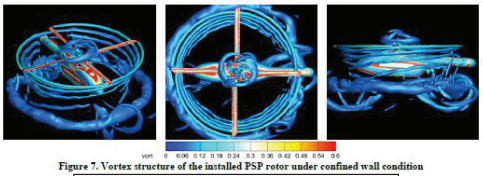
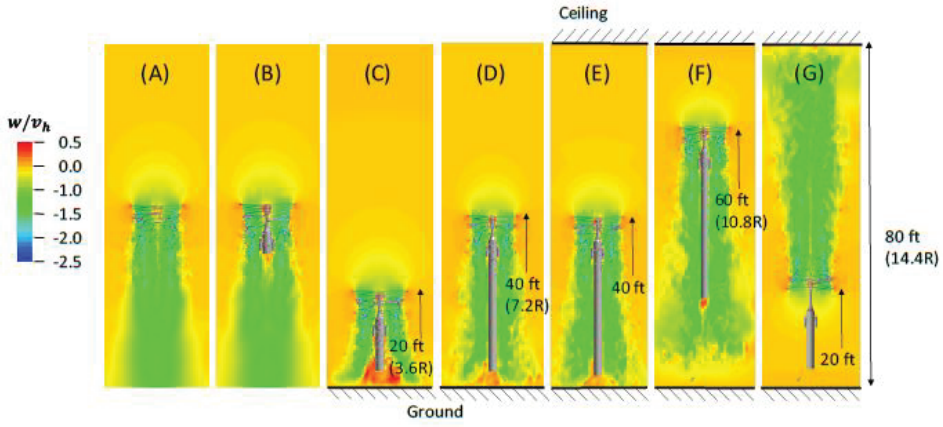


Figure 7. Vortex structure of the installed PSP rotor under confined wall condition

Park, S., Kwon, O., SciTech 2020

Facility Effects



Jain, R., SciTech 2018

HPW Focus: (vi) Transition Modeling

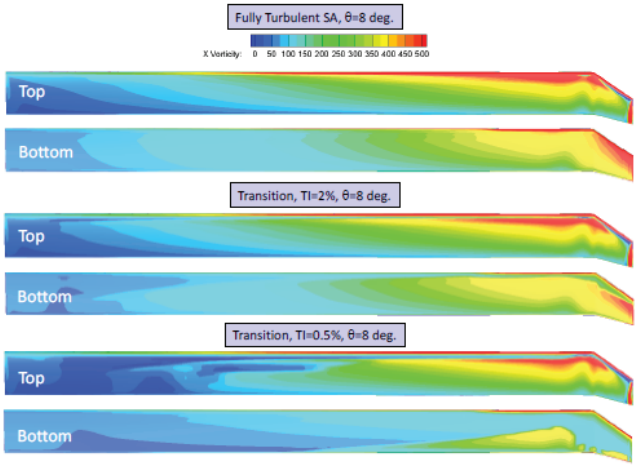
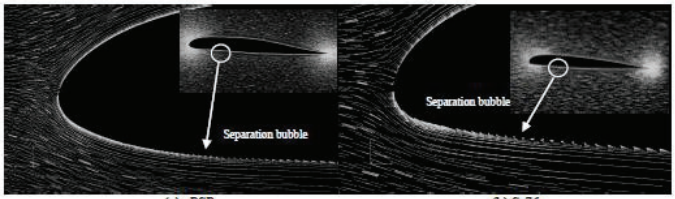


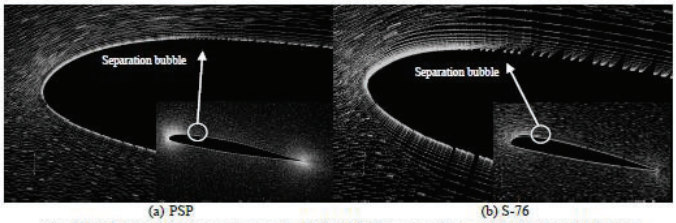
Figure 18 Transition location (span-wise vorticity), θ=8 deg.

Min, B.Y., Reimann, C., Wake B., Jee, S., and Baeder, J., SciTech 2018



(a) PSP (b) S-76

Fig. 12 Predicted laminar separation bubbles on the PSP and S-76 lower surfaces at r/R = 0.75 and θ = 4°



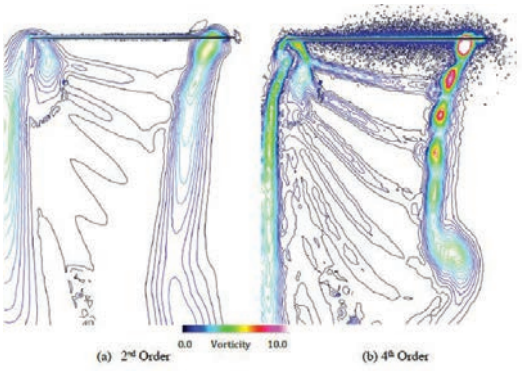
(a) PSP (b) S-76

Fig. 13 Predicted tip flow separations on the PSP and S-76 upper surfaces at r/R = 0.90 and at θ = 12°

Zhao, Q., Wang, J., and Sheng, C., SciTech 2018

HPW Focus: (vii) Numerical Methods & Fidelity

High-Order WENO



Sheng, C., Zhao, Q., and Baugher, S., SciTech 2020

Rotational and SU/PG Methods

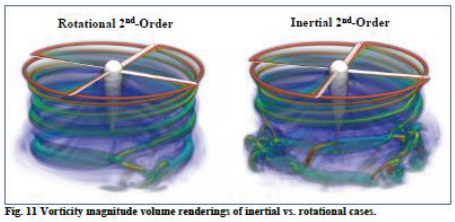


Fig. 11 Vorticity magnitude volume renderings of inertial vs. rotational cases.

Abras, J., Glasby, R., Holst, K., and Hariharan, N., SciTech 2021

DG Methods

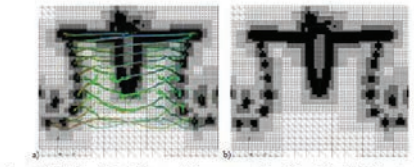


Figure 8. WAKE3D result for S-76 rotor with the swept-tapered tip at Mtip=0.6 in the YZ plane using p_{max}=3. a) Iso-surface of velocity magnitude showing the wake b) off-body mesh showing adapted mesh.

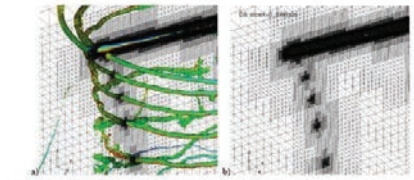
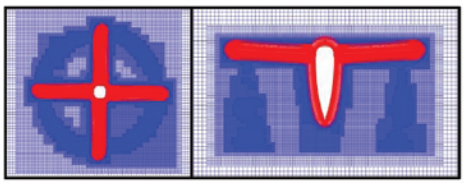


Figure 9. WAKE3D result for the S-76 rotor with the swept-tapered tip at Mtip=0.6 using p_{max}=3 a) Iso-surface of velocity magnitude b) off-body mesh showing AMR capability.

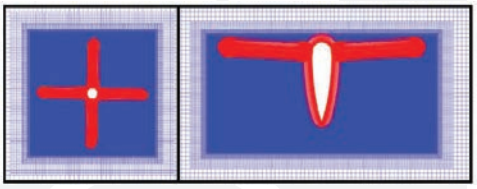
Kara, K., Kirby, A., and Mavriplis, D., SciTech 2020

HPW Focus: (viii) Computational Strategies

Structured Near-Body Cartesian Off-Body

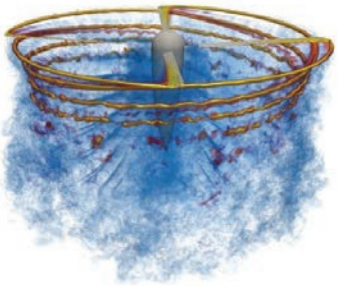


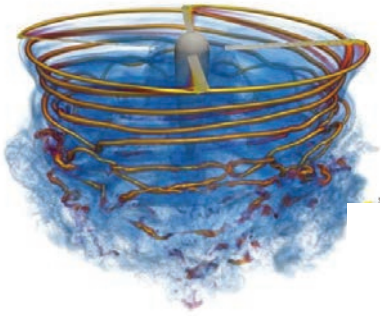
Adaptive Mesh Refinement

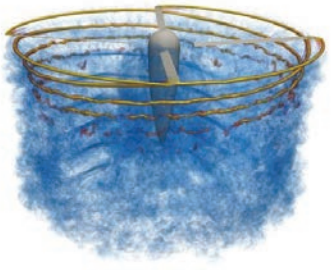


Strand Near-Body Cartesian Off-Body

HPCMP CREATE™-AV HELIOS

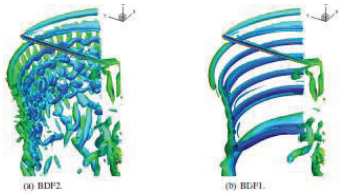






Abras, J., Narducci, R., and Hariharan, N., SciTech 2020

HPW Focus: (ix) Wake Physics: Preservation & Breakdown



Lee, B., and Baeder, J., SciTech 2021

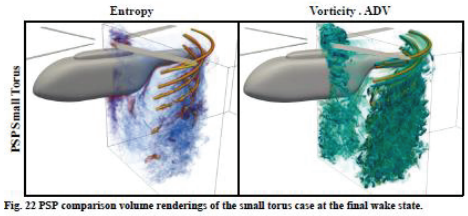
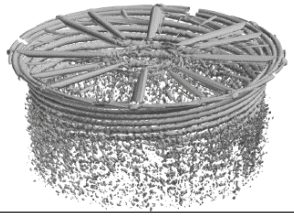


Fig. 22 PSP comparison volume renderings of the small torus case at the final wake state.



Mobley, F., Carnes, J., and Coder, J., SciTech 2021

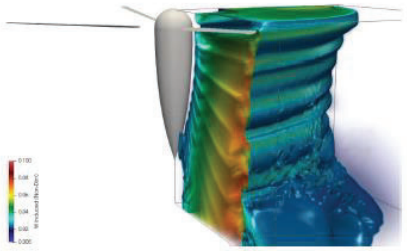
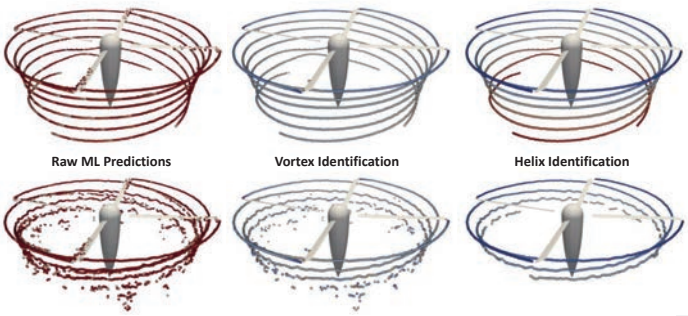


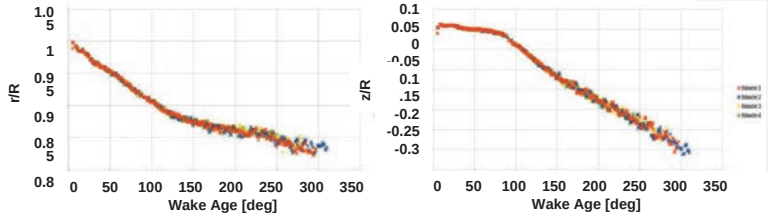
Fig. 28 Volume rendering of the shear layer in the S-76 baseline simulation around revolution 7.5.

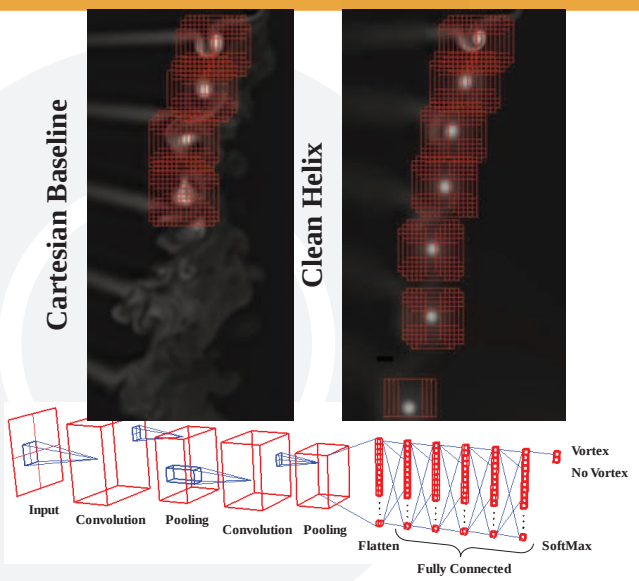
Abras, J., Narducci, R., and Hariharan, N., SciTech 2021

Caprace, D., Winckelmans, G., Chatelain, P., SciTech 2021

HPW New Tech: (i) Machine Learning Based Automated Vortex Tracking

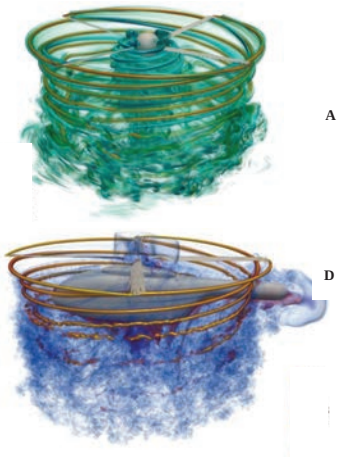




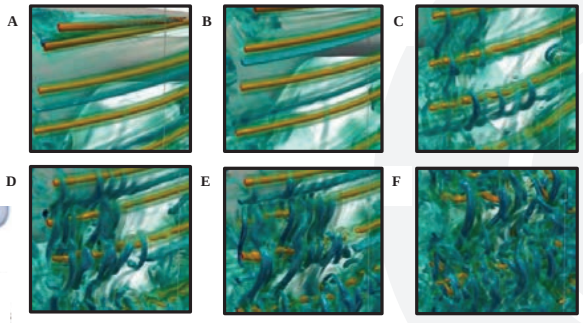


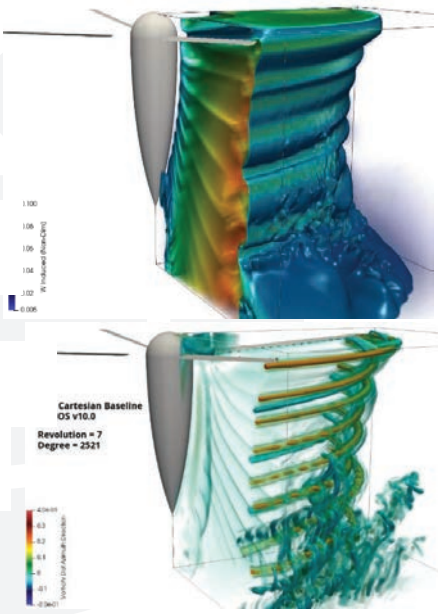
Abras, J., and Hariharan, N., SciTech 2021

HPW New Tech: (ii) Physics Inference: Advanced Visualization Techniques



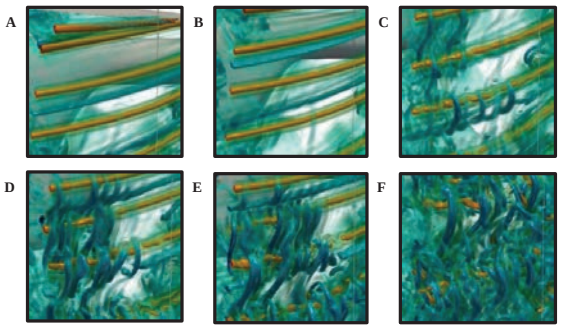
Volume Rendering



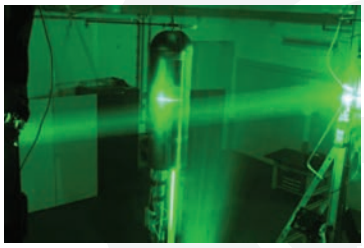


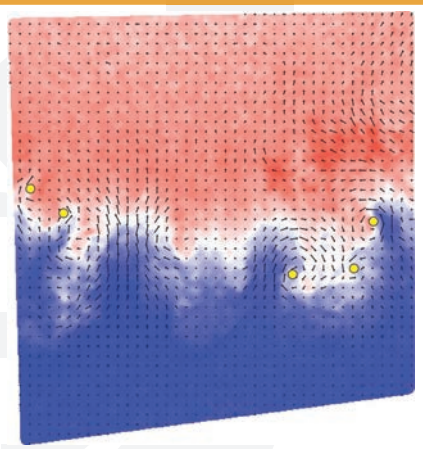
Abras, J., Narducci, R., and Hariharan, N., SciTech 2021

HPW New Tech: (iii) Wake Experiments for Breakdown



Abras, J., et al., HPW, SciTech 2021

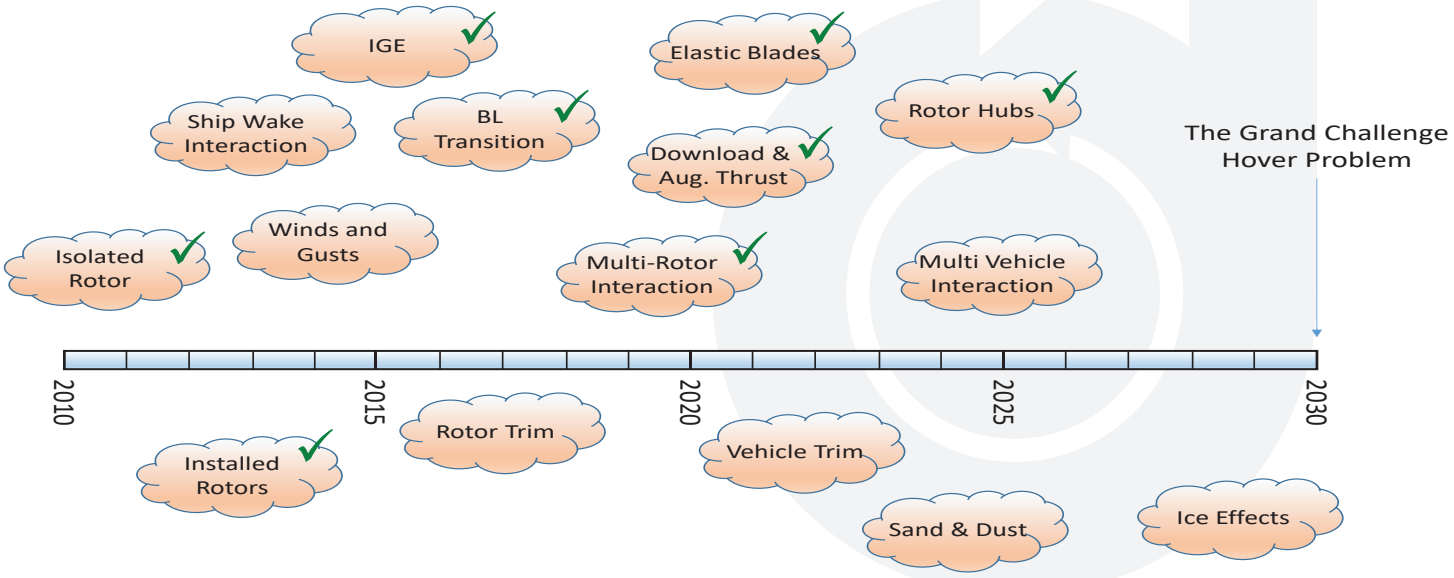




DLR

Heinz, A, et al., " Influence of Configurational Parameters on the Vortex System of a Rotor in Hover," HPW, SciTech 2024

Elements addressed in HPW

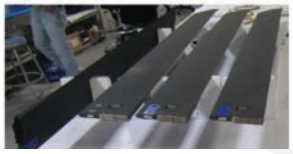


HPW Advocacy: NASA/Army HVAB Hover Tests

ARTS Test Stand in Hover Chamber

Articulated Hub

NFAC 80- by 120-

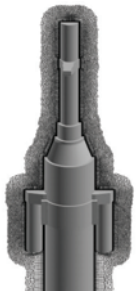


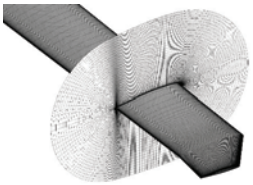
HVAB Blades

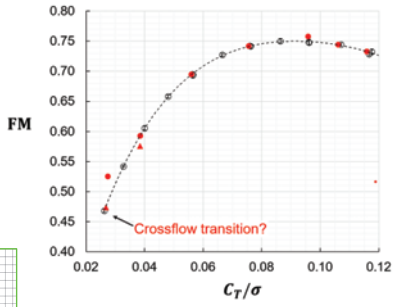
HVAB Rotor in 80- by 120-Foot NFAC wind tunnel

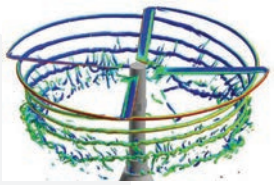
Norman, T., SciTech 2018

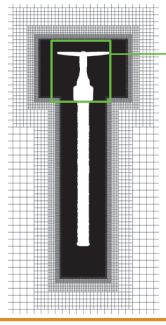
2024 HPW: HVAB CFD-CSD Blind Prediction Comparisons

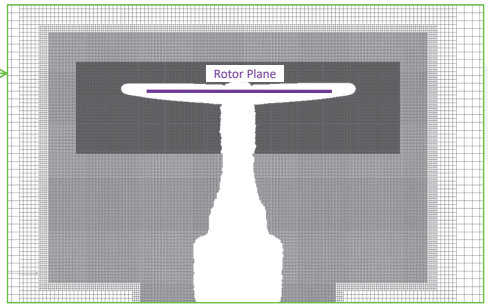




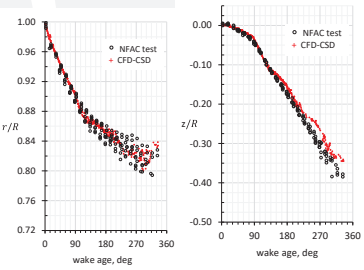








HPCMP CREATE™-AV Helios

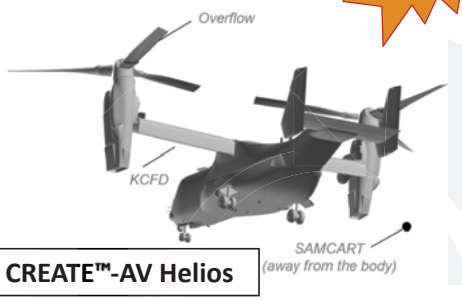


Radial & Axial position

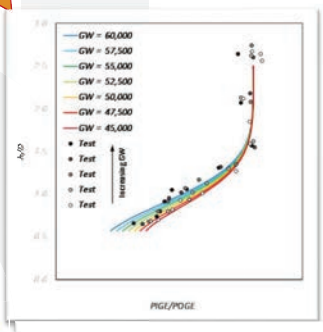
Jain, R., "CFD-CSD Pre-test Hover Predictions Validation for the HVAB Rotor," HPW, SciTech 2024

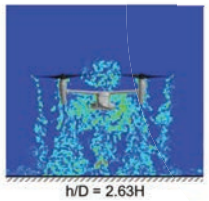
2024 HPW: V22 Flight Test Predictions

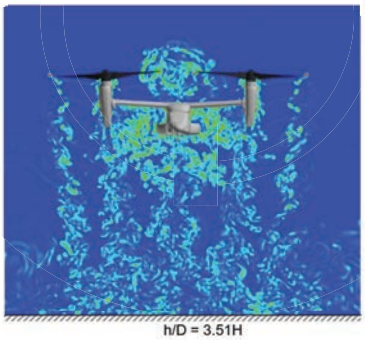
100th Paper!!!!

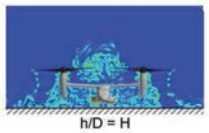


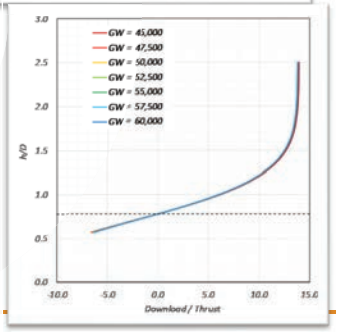
HPCMP CREATE™-AV Helios





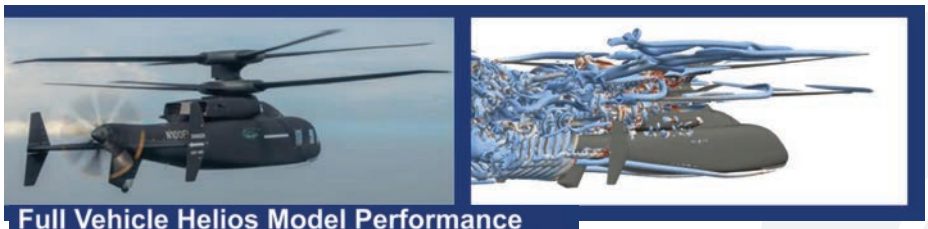




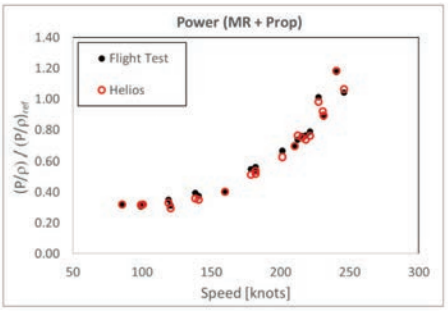


Robert Narducci, John Liu, Robert Mayer, Adam Wells, Forrest Mobley, " CFD Simulation of a Hovering Tiltrotor In Ground Effect ," HPW, SciTech 2024

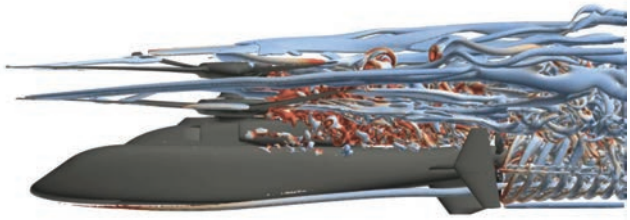
Putting it all together: State-of-the-Art

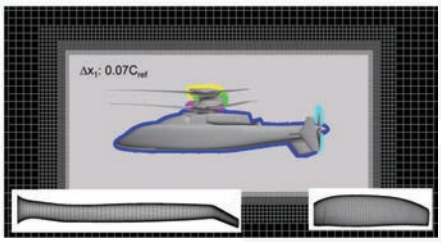


Full Vehicle Helios Model Performance Correlation with SB>1 Defiant® Flight Test



HPCMP CREATE™-AV Helios





SIKORSKY
A LOCKHEED MARTIN COMPANY

Byung-Young Min, Jeewoong Kim, Vera Klimchenko, Jacob C. Neiswonger, Daniel Griffiths, Brian E. Wake

Applied Aerodynamics

APA

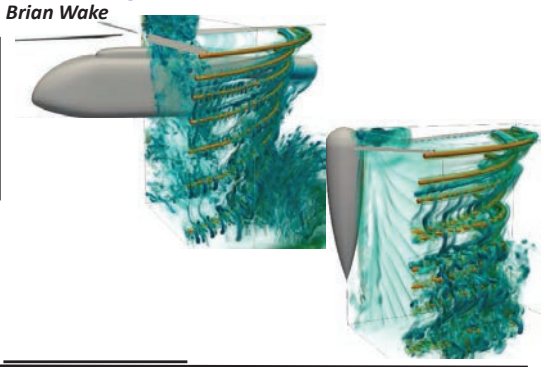
Technical Committee

HPW – Hover Prediction Workshop

Steering Group: Jennifer Abras, Nathan Hariharan, Rohit Jain, Robert Narducci, Brian Wake

Purpose

- Bring together government institutions, industry and academia
- Assess current state-of-the-art across industry, government agencies and academia.
- Scope critical challenges in consistently, and accurately predicting rotorcraft hover and forward flight.
- Act as leading catalyst in the development of computational methods for solving rotorcraft hover problems
- AIAA HPW | Hover Prediction Workshop | Rotorcraft Hover (aiaa-hpw.org)



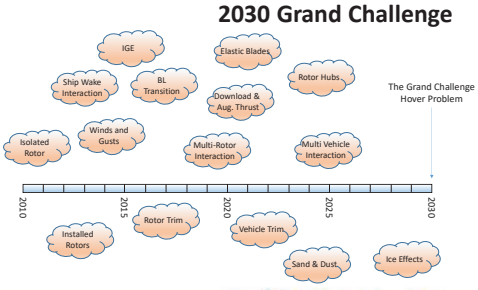
Impact/Accomplishments

- 20+ Hover Prediction Workshop Special Sessions,SciTech 2014-2024
- 100+ papers by 87 authors from 19 organizations around the world (7 Universities, 6 Industries, 6 Government Agencies)
- Special section in the Journal of Aircraft (2018)
- Contributing catalyst for the NASA/Army comprehensive HVAB hover tests (2021-22)
- Enhanced State-of-the-art: Computational modeling requirements for accurate hover integrated load prediction, importance of transition effects, understanding of numerical wake-breakdown, visualization, aero-elastics

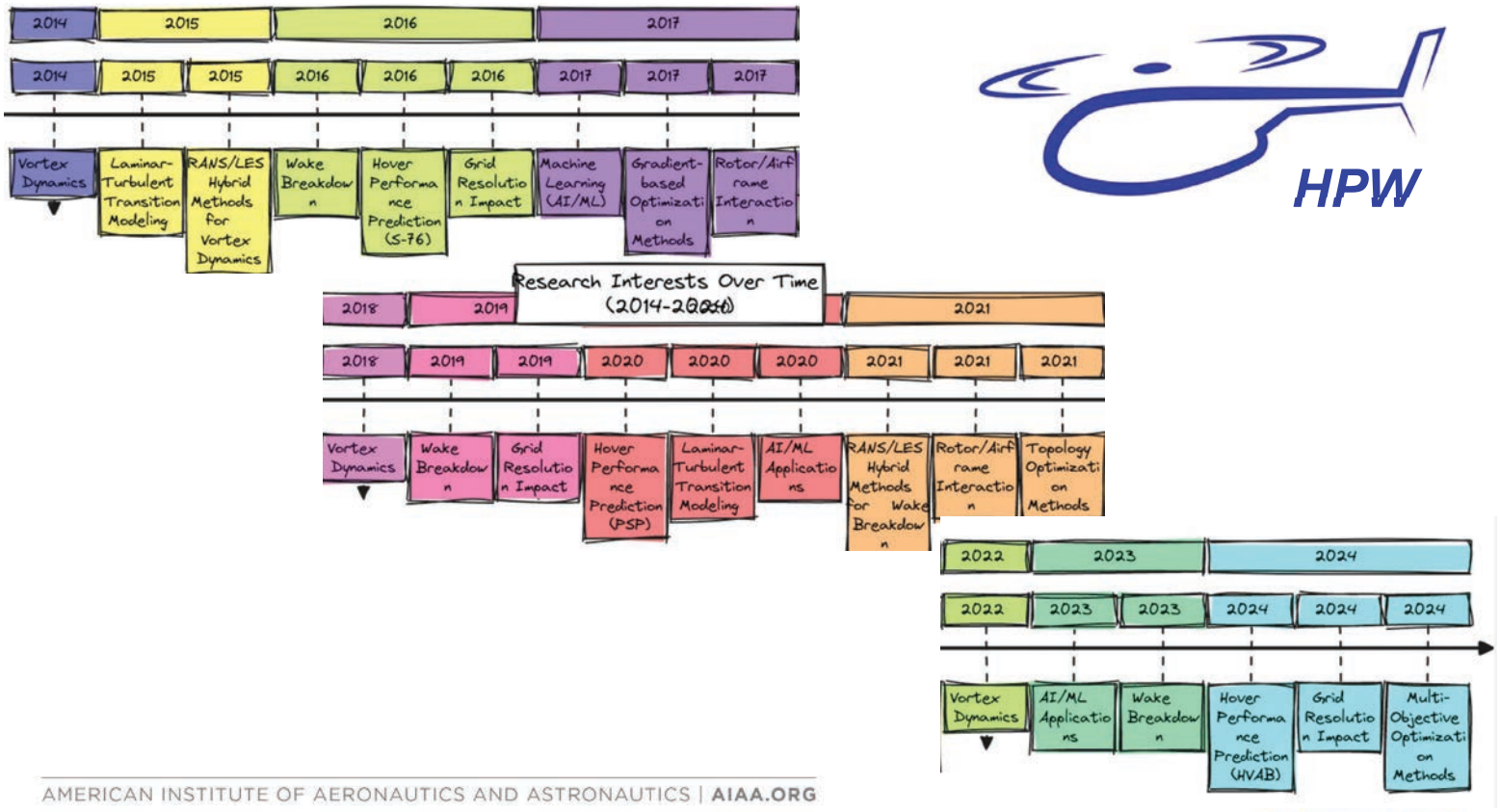
Future Plans

- NASA/Army HVAB Hover Predictions
- Hover Download Predictions
- Full Rotorcraft Hover 2030 Grand Challenge
- eVTol Elements

2030 Grand Challenge



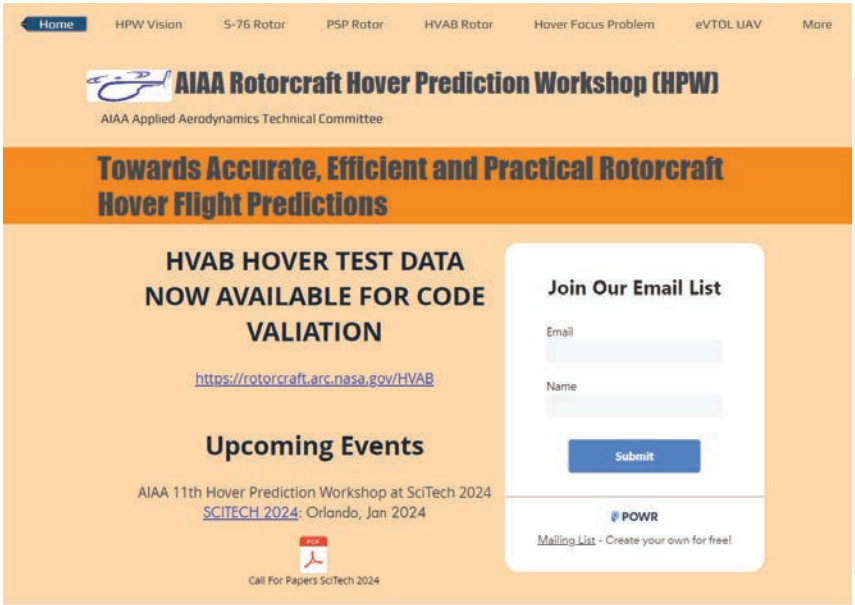
AIAA
Shaping the Future of Aerospace



AIAA The World's Forum for Aerospace Leadership

HPW

HPW Website



- The HPW meets twice a year
  - Winter: SciTech
  - Summer: Aviation
- www.aiaa-hpw.org
- Email correspondence

1. Hariharan, N., Egolf, T.A., Sankar, L.N. "Simulation of Rotor in Hover: Current State and Challenges," AIAA 2014-0041, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
2. Jung, M.K., Hwang, J.Y., Kwon, O.J. "Assessment of Rotor Aerodynamic Performances in Hover Using an Unstructured Mixed Mesh Method," AIAA 2014-0042, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
3. Brocklehurst, A., Barakos, G.N. "Evaluating Tail Rotor Tip Shapes using Computational Fluid Dynamics," AIAA 2014-0043, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
4. Sheng, C., Zhao, Q., Wang, J. "S-76 Rotor Hover Prediction Using U2NCLE Solver," AIAA 2014-0044, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
5. Baeder, J.D., Medida, S., Kalra, T.S. "OVERTURNS Simulations of S-76 Rotor in Hover," AIAA 2014-0045, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
6. Jain, R.K., Potsdam, M.A. "Hover Predictions on the Sikorsky S-76 Rotor using Helios," AIAA 2014-0207, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
7. Narducci, R. "OVERFLOW Simulation of Rotors in Hover: The Boeing Company," AIAA 2014-0208, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
8. Tadghighi, H. "Helios Simulation of Rotors in Hover: The Boeing Company," AIAA 2014-0209, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
9. Marpu, R.P., Sankar, L.N., Egolf, T.A., Hariharan, N. "Analysis of a Rotor in Hover using Hybrid Methodology," AIAA 2014-0210, AIAA SciTech 52nd Aerospace Sciences Meeting, 13-17 January 2014, National Harbor, Maryland.
10. Hariharan, N., Egolf, T.A., Narducci, R., Sankar, L.N., "Helicopter Rotor Aerodynamic Modeling in Hover: AIAA Standardized Hover Evaluations," AIAA 2015-1242, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
11. Narducci, R., "Hover Performance Assessment of Several Tip Shapes using OVERFLOW," AIAA 2015-1243, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
12. Jain, R., "Hover Predictions for the S-76 Rotor with Tip Shape Variation using CREATE™-AV Helios," AIAA 2015-1244, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
13. Anusonti-Inthra, P., "The Effects of Turbulence Modelings on CFD Simulations of S76 Hovering Rotor," AIAA 2015-1245, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
14. Hwang, J.Y., Choi, J.H., Kwon, O.J., "Assessment of S-76 Rotor Aerodynamic Performance in Hover on Unstructured Mixed Meshes," AIAA 2015-1246, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
15. Min, B.Y., Wake, B., "Analysis of a Hovering Rotor using UT-GENCAS: A Modified Hybrid Navier-Stokes/Free-Wake Method," AIAA 2015-1247, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
16. Whitehouse, G.R., Wachspress, D.A., Quackenbush, T.R., "Predicting the Influence of Blade Tip Shape on Hovering Rotor Performance with Comprehensive Analyses," AIAA 2015-1248, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
17. Abras, J.N., Hariharan, N., "Comparison of CFD Hover Predictions on the S-76 Rotor," AIAA 2015-1711, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.
18. Garcia, A.J., Barakos, G.N., "Hover Predictions on the S-76 Rotor using HMB2," AIAA 2015-1712, AIAA SciTech 53rd Aerospace Sciences Meeting, 5-9 January 2015, Kissimmee, Florida.

HPW

HPW AIAA Papers: 2014-2015

AIAA Shaping the Future of Aerospace

1. Hariharan, N., Narducci, R., Egolf, T.A., Reed, E. "Helicopter Rotor Aerodynamic Modeling of S-76 Rotor with Tip-Shape Variations," AIAA 2016-0031, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
2. Jain, R. "A Comparison of CFD Hover Predictions for the Sikorsky S-76 Rotor," AIAA 2016-0032, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
3. Abras, J., Hariharan, N. "Performance Impact of Tip Shape Variations on the S-76 Rotor Using kCFD," AIAA 2016-0298, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
4. Barakos, G., Jimenez-Garcia, A. "Hover Predictions of the S-76 Rotor using HMB2 – Model to Full Scale," AIAA 2016-0299, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
5. Hwang, J., Choi, J., Kwon, O. "Assessment of S-76 Rotor Hover Performance in Ground Effect Using an Unstructured Mixed Mesh Method," AIAA 2016-0033, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
6. Jacobson, K., Grubb, A., Smith, M. "Performance and Physics of an S-76 Rotor in Hover with Non-Contiguous Hybrid Methodologies," AIAA 2016-0302, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
7. Min, B., Wake, B. "Parametric Validation Study for a Hovering Rotor Using UT-GENCAS," AIAA 2016-0301, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
8. Duque, E., Toyoda, M., Burklund, M., Hariharan, N., Narducci, R., Stone, C. "Direct Comparison of Hover Prediction Workshop Results," AIAA 2016-0035, AIAA SciTech 54th Aerospace Sciences Meeting, 4-8 January 2016, San Diego, California.
9. Egolf, T.A., Hariharan, N., Narducci, R., Reed, E., "AIAA Standardized Hover Simulation: Hover Performance Prediction Status and Outstanding Issues," AIAA-2017-1429, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
10. Narducci, R., "Comparison of Steady-State and Time-Dependent Solutions for the S-76 Model-Scale Rotor in Hover," AIAA-2017-1430, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
11. Abras, J.N., Hariharan, N., "Parameter Studies on the S-76 Rotor Using HELIOS," AIAA-2017-1431, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
12. Coder, J.G., "OVERFLOW Rotor Hover Simulations Using Advanced Turbulence and Transition Modeling," AIAA-2017-1432, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
13. Lee, B., Govindarajan, B., Baeder, J.D., "Methods for Efficient Resolution of Vortical Structures of an S-76 Rotor in Hover," AIAA-2017-1664, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
14. Vieira, B.A., Kinzel, M.P., Maughmer, M.D., "CFD Hover Predictions Including Boundary-Layer Transition," AIAA-2017-1665, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
15. Garcia, A.J., Colonia, S., Barakos, G.N., "Accurate Predictions of Hovering Rotor Flows Using CFD," AIAA-2017-1666, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
16. Wong, T.C., "Application of CREATE™-AV Helios in an Engineering Environment: Hover Prediction Assessment," AIAA-2017-1667, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
17. Duque, E.P.N., Toyoda, A., Burklund, M.D., Hariharan, N., "Standardized Post-Processing and Visualization of Participants' Simulations of a Rotor in Hover," AIAA-2017-1668, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.
18. Zhou, C., Sankar, L.N., Eschcol, R.M., Kim, J., "Application of Hover Prediction Methodologies to Anhedral Tip Shapes," AIAA-2017-1870, AIAA SciTech 55th Aerospace Sciences Meeting, 9-13 January 2017, Grapevine, TX.

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HPW AIAA Papers: 2016-2017

AIAA Shaping the Future of Aerospace

1. Jain, R., "Effect of Facility Walls and Blade Aeroelasticity on PSP Rotor Hover Performance Predictions," AIAA 2018-0305, AIAA SciTech 56th Aerospace Sciences Meeting, 8-12 January 2018, Kissimmee, FL.
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J. Gordon Leishman

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Jennifer N. Abras and Nathan Hariharan

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