NASA Advanced Supercomputing Division
Advanced Modeling & Simulation (AMS)
Seminar Series

U.S. ARMY RDECOM

Originally presented at AHS International Technical Meeting
Aeromechanics Design for Transformative Vertical Lift
San Francisco, CA

Assessment of Rotorcraft Download Using CREATE™-AV Helios

Approved for public release; distribution unlimited.
Review completed by the AMRDEC Public Affairs Office (PR3510, 19 Dec 2017)

AMRDEC

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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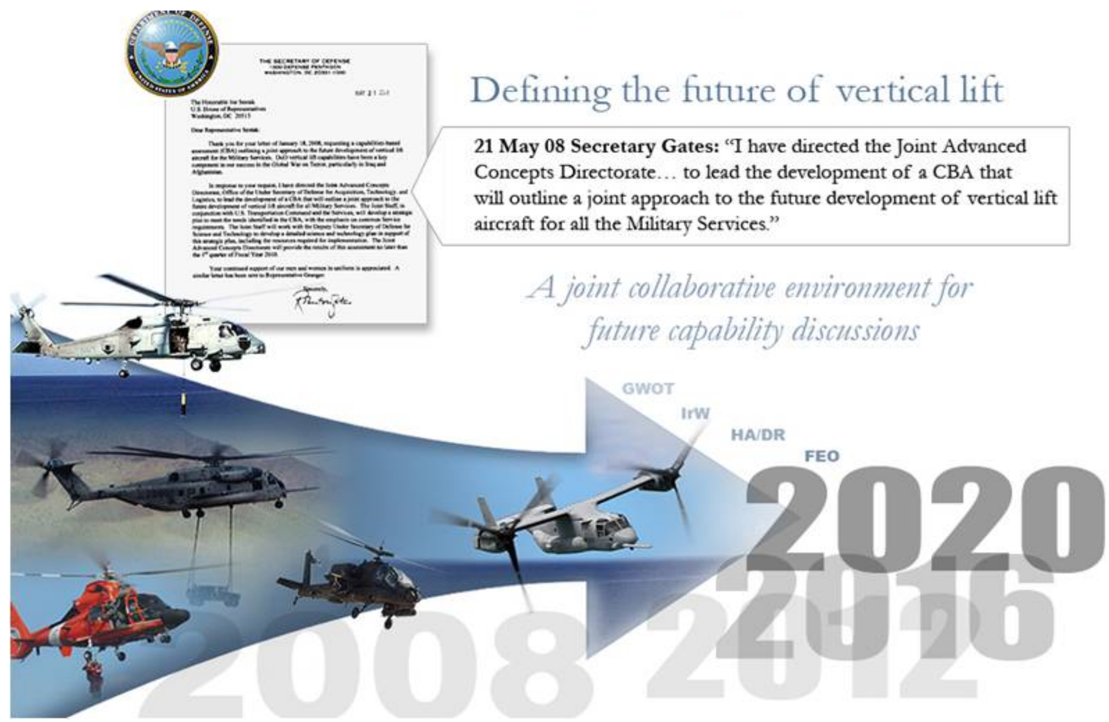
Oct 11 2018

Presentation Outline

- **Motivation and Objectives**
  - Army JMR TD Program
  - Past download prediction efforts
- **JVX Joint Vertical Experiment**
- **Computational Model**
  - Isolated rotor
  - Rotor/Wing/Flap/Hub/Image Plane combination
  - Code comparison
- **Concluding Remarks**

Army JMR TD Program

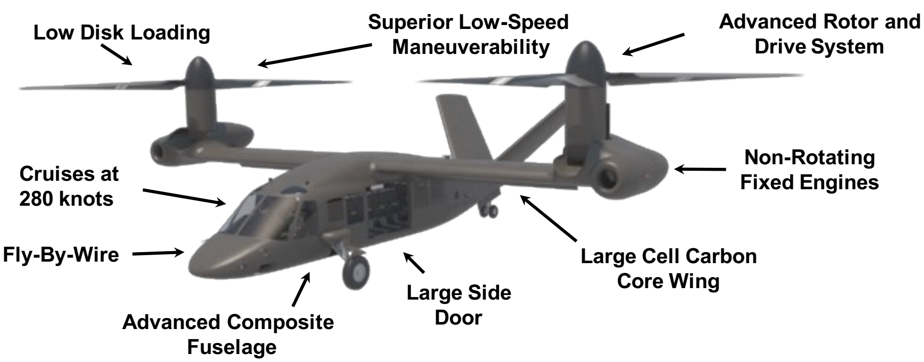
- **Joint Multi-Role (JMR) Technology Demonstrator (TD)**
- **Purpose: Demonstrate transformational vertical lift capabilities to prepare the DoD for decisions regarding the replacement of the current vertical lift fleet**



- **Requirements**
  - 230+ knots
  - 6K/95F hover at mission payload
  - 424 km combat radius with 30min loiter
  - Ability to self deploy with 2100nm range
- **Products**
  - Technology maturation plans
  - Cost analysis for future capabilities
  - Two demonstrator test bed aircraft

JMR TD - Flight Demonstrators

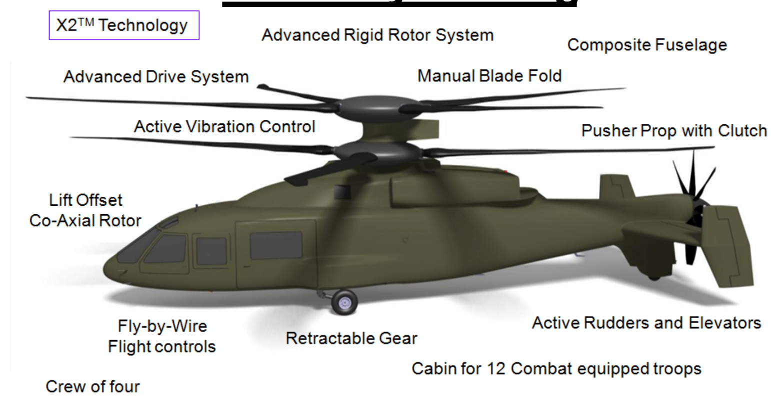
Bell Helicopter



Demonstrating technologies that provide affordable tilt-rotor access to Army capability sets

- Fly-by-wire flight control system
- Flight envelope protection
  - Structural load limiting
  - Conversion corridor protection
- Designed for low-cost manufacturing
  - Broad goods skin lay-up & yoke
  - Large cell carbon core
  - Bonded skin assemblies
- Performance
  - 280 knots cruise
  - HOGE 6K95
  - Designed to meet ADS-33 Level 1 yaw, pitch and roll quickness

Sikorsky-Boeing

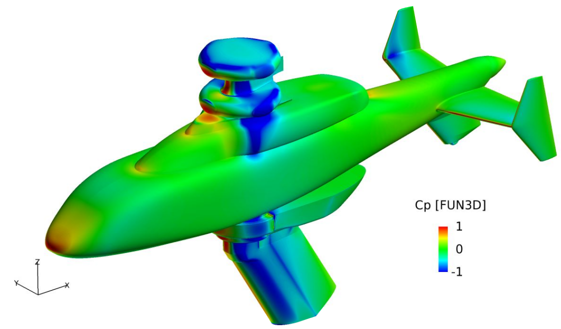


Demonstrating technologies that provide affordable coaxial, lift-offset compound access to Army capability sets

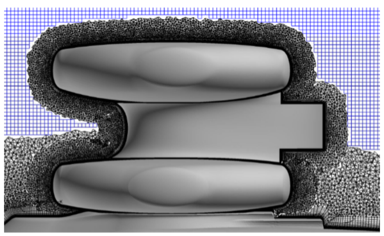
- Fly-by-wire flight controls
- Active vibration control
- Configuration
  - Lift Offset Coaxial Rotor
  - Pusher Prop
  - Variable RPM drive system
- Performance
  - 250 knots cruise
  - HOGE 6K95
  - Low & medium speed maneuverability

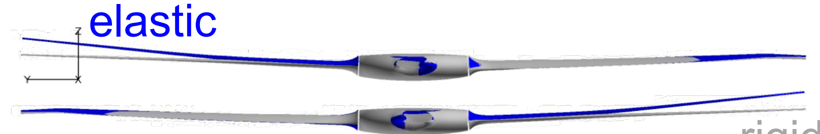
Helios Calculations of Sikorsky-Boeing SB>1 “Defiant”

- Airframe forces/moments
- Effect of rotating hubs and turbulence modeling
- Windtunnel model validation
- Interactional aerodynamics of complete flight configuration (airframe, rotors, propeller)
- On-going monthly meetings with Sikorsky-Boeing

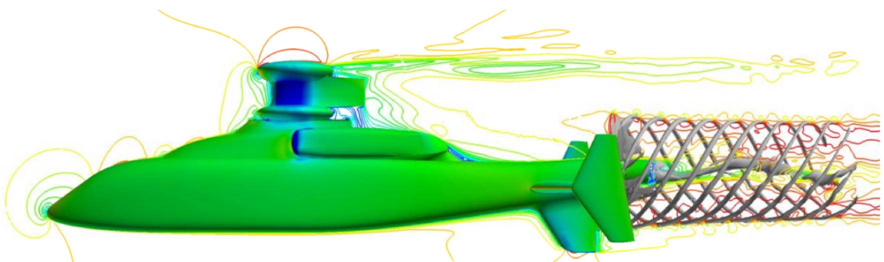


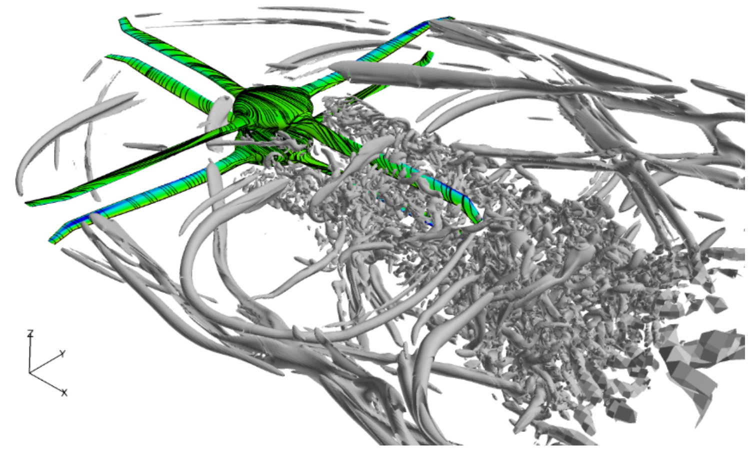
WT model





front view

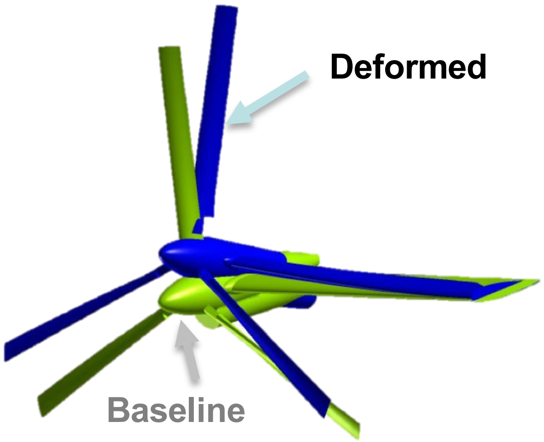




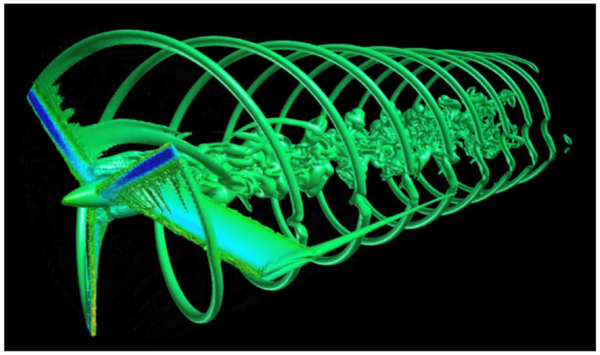
Helios Calculations of Bell V-280 "Valor"

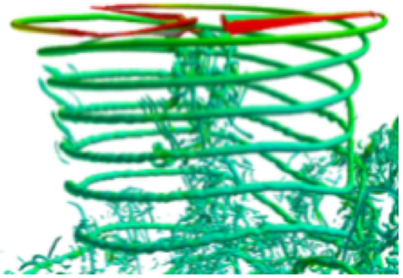
- Tiltrotor download
- Whirlflutter analysis
- Windtunnel model validation
- Interactional aerodynamics of complete flight configuration (airframe, rotors, proprotors)
- On-going monthly meetings with Bell

V-280 First flight – Dec 2017
Courtesy Bell Helicopter



XV-15 - Courtesy M. Floros, ARL





Helicopter Download

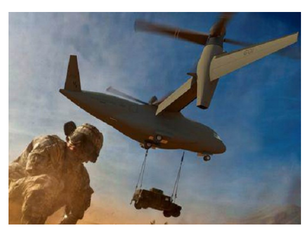
- **Helicopter download is the force imposed on the fuselage that counters the thrust of the rotor**

- **Small changes in download can have a large impact on hover performance**
  - For large-scale military helicopter like CH-47 or V-22, 1% thrust improvement in download increases payload capacity by 1-2 crewmembers

- **Helios is being used to assess download on new configurations**
  - Novel configurations, distributed propulsion systems

AVX Aircraft Co
Co-axial/ducted fans

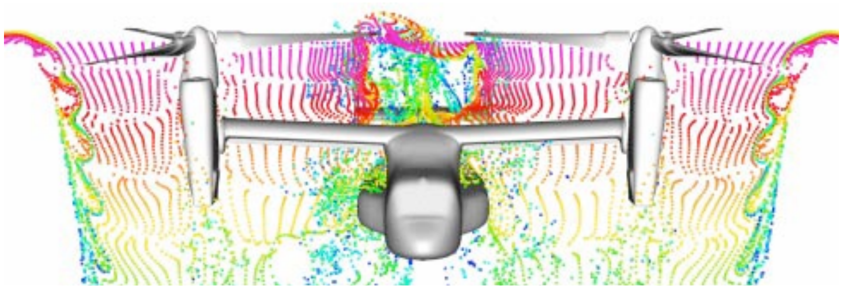
Bell
Tiltrotor



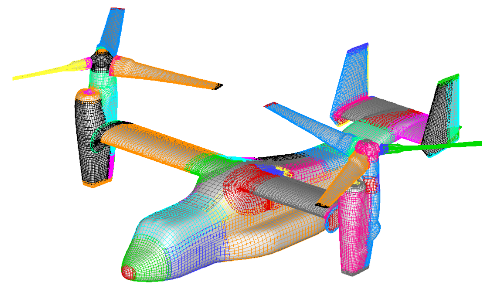
Karem
Tilt rotor/wing

Sikorsky/Boeing
Co-axial/propulsor

Motivation & Objectives



- **CFD download calculations are difficult**
  - Separated bluff body flow – difficult for most solvers
  - Long and expensive calculations – many revs typically required



Potsdam & Strawn, AHS J, 2005

- **Previous CFD download validations run before Helios existed**
  - OVERFLOW-D, early 2000's
  - Coarse meshes, primitive turbulence models

- **Develop modern set of best practices for download prediction with Helios**
  - Investigate different near-body solvers – FUN3D, OVERFLOW, mStrand (Verification)
  - Compare computed results to JVX experiment (0.658-scale V-22) (Validation)

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- **JVX Joint Vertical Experiment**
- Computational Model
  - Isolated rotor
  - Rotor/Wing/Flap/Hub/Image Plane combination
  - Code comparison
- Concluding Remarks



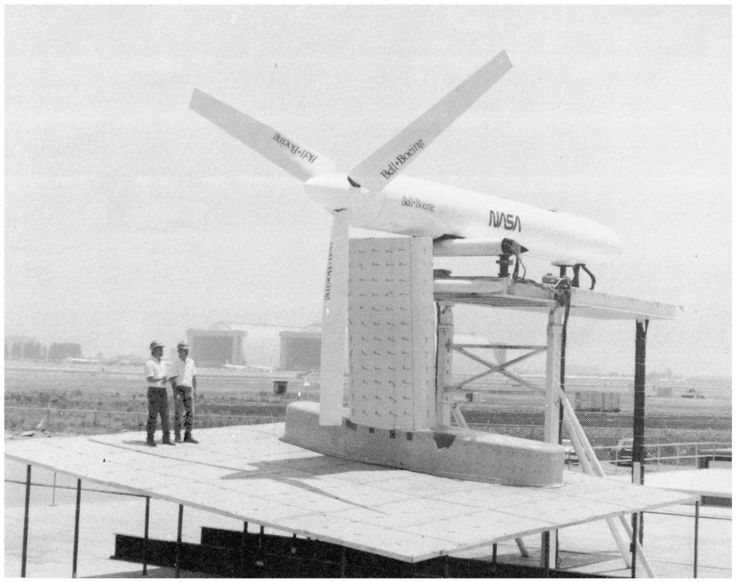

Joint Vertical Experiment (JVX)

- **0.658-scale V-22 development rotor tested at the NASA Ames Outdoor Aerodynamics Research Facility (OARF)***

Isolated

RPM = 625
M_{tip} = 0.675
Re_{tip} = 6.1 Million

Combined
Rotor/Wing/Flap/Image Plane



RPM = 380
M_{tip} = 0.409
Re_{tip} = 3.7 Million
Flap = 67 deg

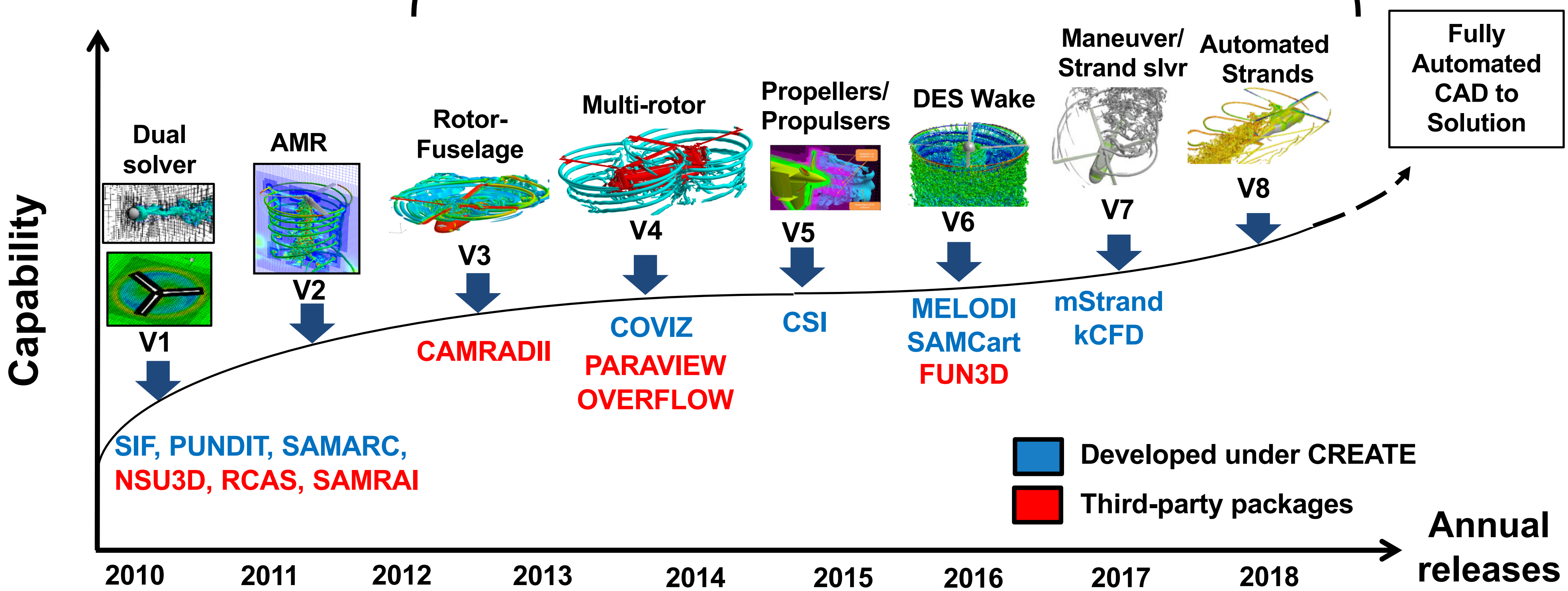
* Felker, Signor, Young, Betzina
NASA TM 89419, 1987

Computational Approach

- **Helios: Rotary-wing product of the DoD's CREATE™-AV program**
  - Relative motion, complex geometry, multi-solver, interfaces with comprehensive codes
  - Targets government rotary-wing acquisition programs

Army programs using Helios

H-47 tandem simulati *Boeing/AED* | AH-64 Apache *Boeing* | H-60 main/tail simulation *Sikorsky/AED* | JMR "Defiant" *Sikorsky/Boeing* | JMR "Valor" *Bell Helicopter* | CH47 – Block II *Boeing/AED/ADD*

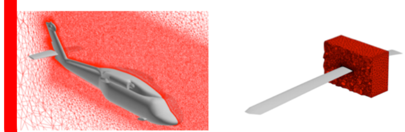


Strand Meshing

Unstructured Structured

1) Grow volume meshes

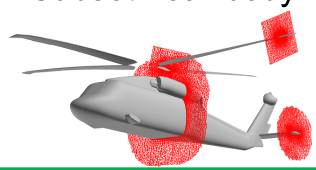
Component meshes



NOT AUTOMATIC

2) Assemble and trim

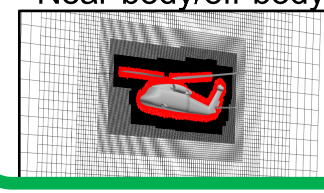
Subset near-body



AUTOMATIC

3) Build dual mesh

Near-body/off-body

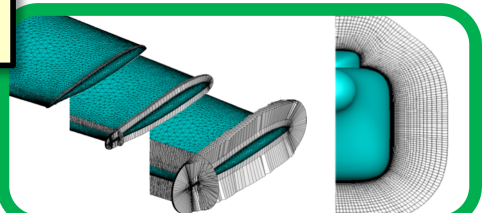


AUTOMATIC

Inputs
- Surface mesh
- Wake spacing

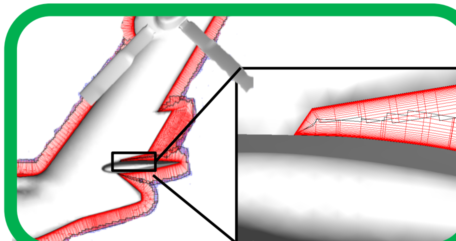
Strand

1) Grow strand volume meshes



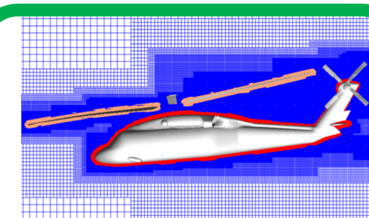
AUTOMATIC

2) Intersect/connect



AUTOMATIC

3) Build dual mesh

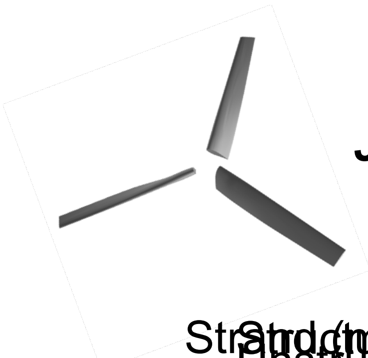


AUTOMATIC

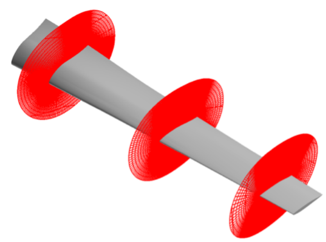
- Hv8 introduces automated runtime parallel near-body strand mesh generation

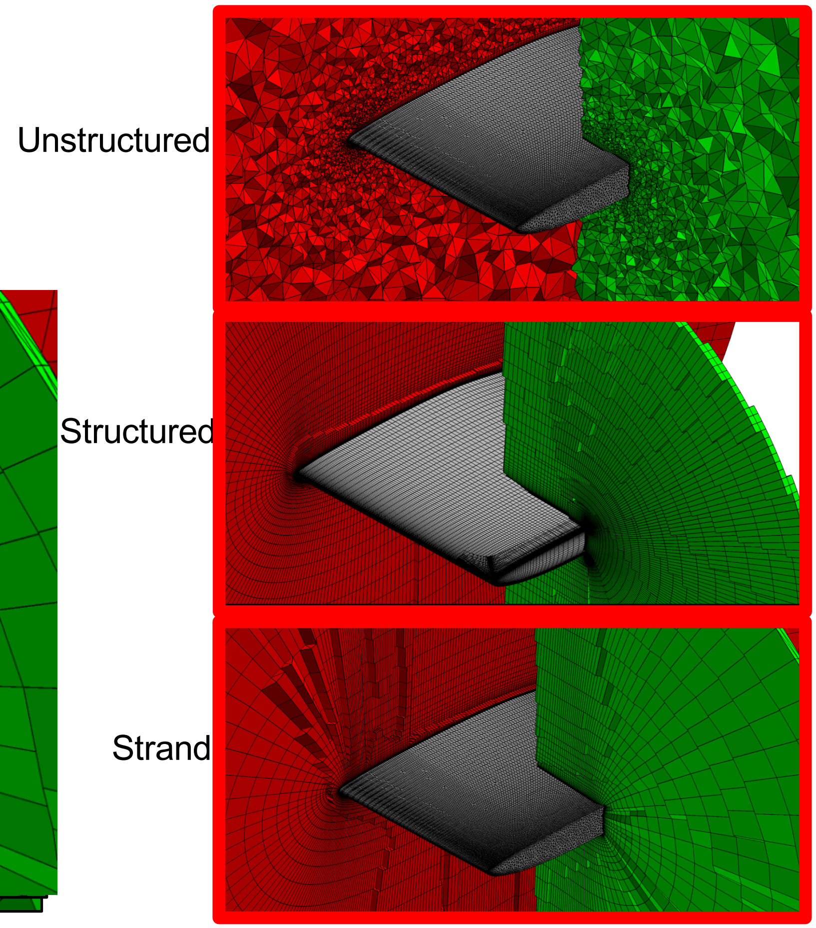
Helios JVX Setup
Isolated Rotor

- **Calculations performed with FUN3D, OVERFLOW, and mStrand near-body solvers**
- **mStrand used automatically generated meshes**
  - Same surface mesh as unstructured

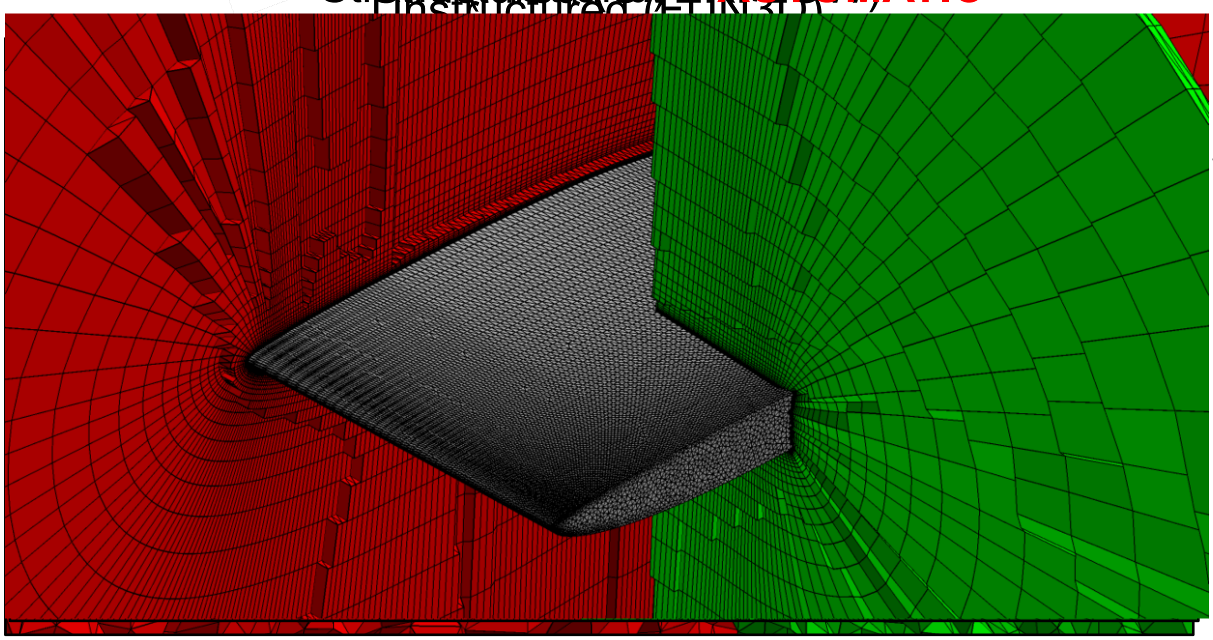


JVX Rotor





AUTOMATIC

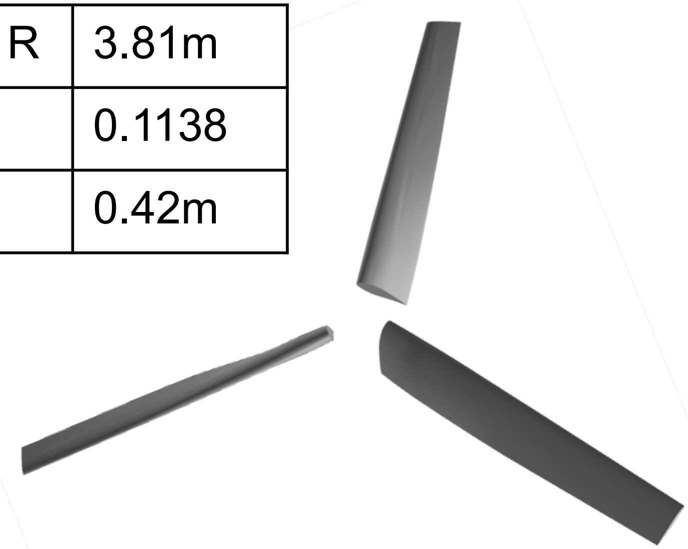


Computational Setup

Isolated Rotor

- **Computational conditions**
  - 10 revs, 0.25 deg timestep
  - Time accurate implicit BDF2
  - Fully turbulent: Spalart Allmaras or kω Shear Stress Transport (SST) models
  - Near-body subset distance = 1 chord

Blade length R	3.81m
Solidity σ	0.1138
Tip chord	0.42m



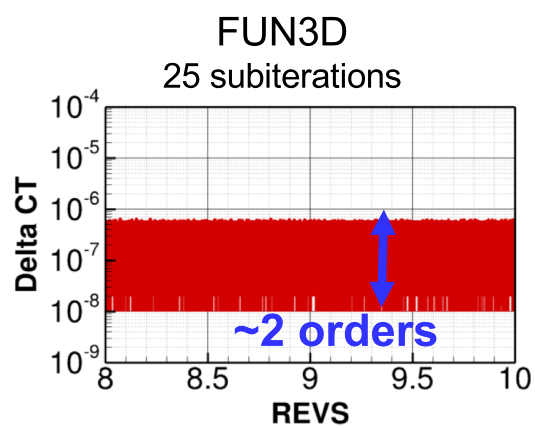
Rotor Mesh Stats

Gridpoints	Blade surf	Blade vol	Rotor Vol
Structured OVERFLOW	128.4K	8.35M	25.1M
Unstructured FUN3D	97.8K	4.32M	13.0M
Strand mStrand	97.8K	4.40M	13.2M

Solver Convergence

- Near-body sub-iterations chosen to achieve average of 2 orders force convergence each timestep
- 10 revs sufficient to converge Figure of Merit variation < 0.25%

Sub-iteration convergence



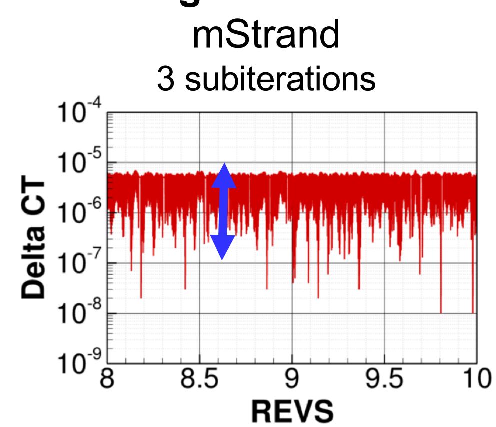
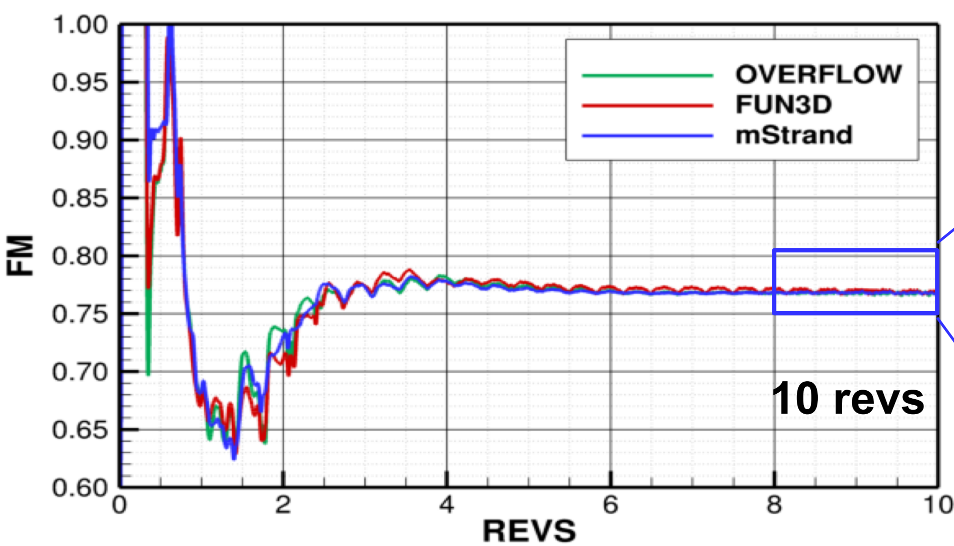
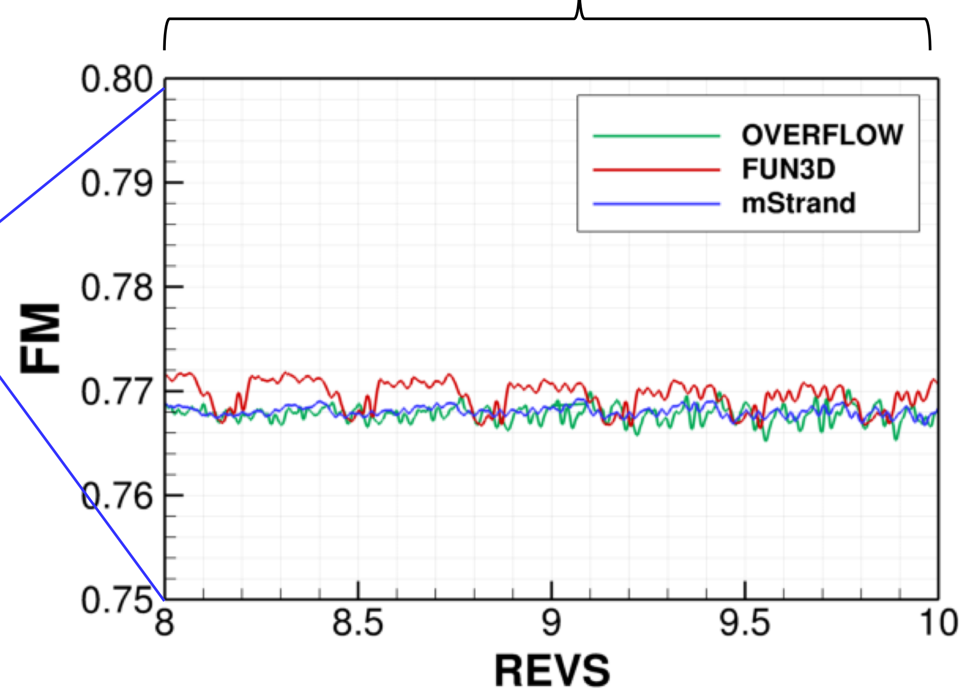


Figure of Merit convergence



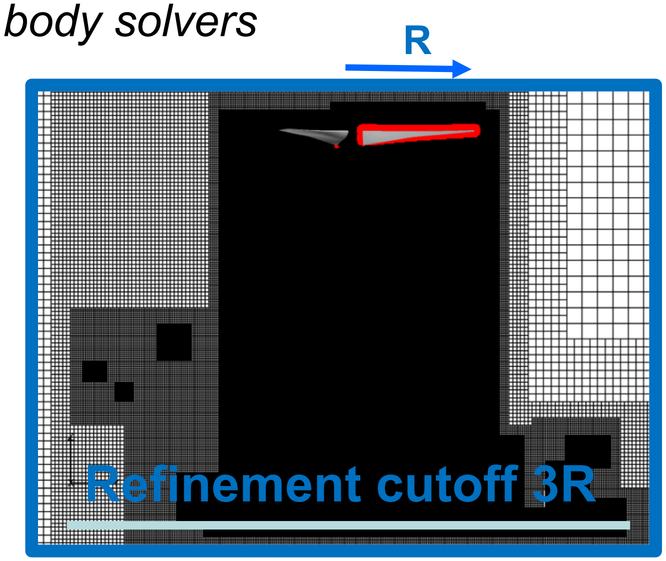
Forces averaged over revs 8-10



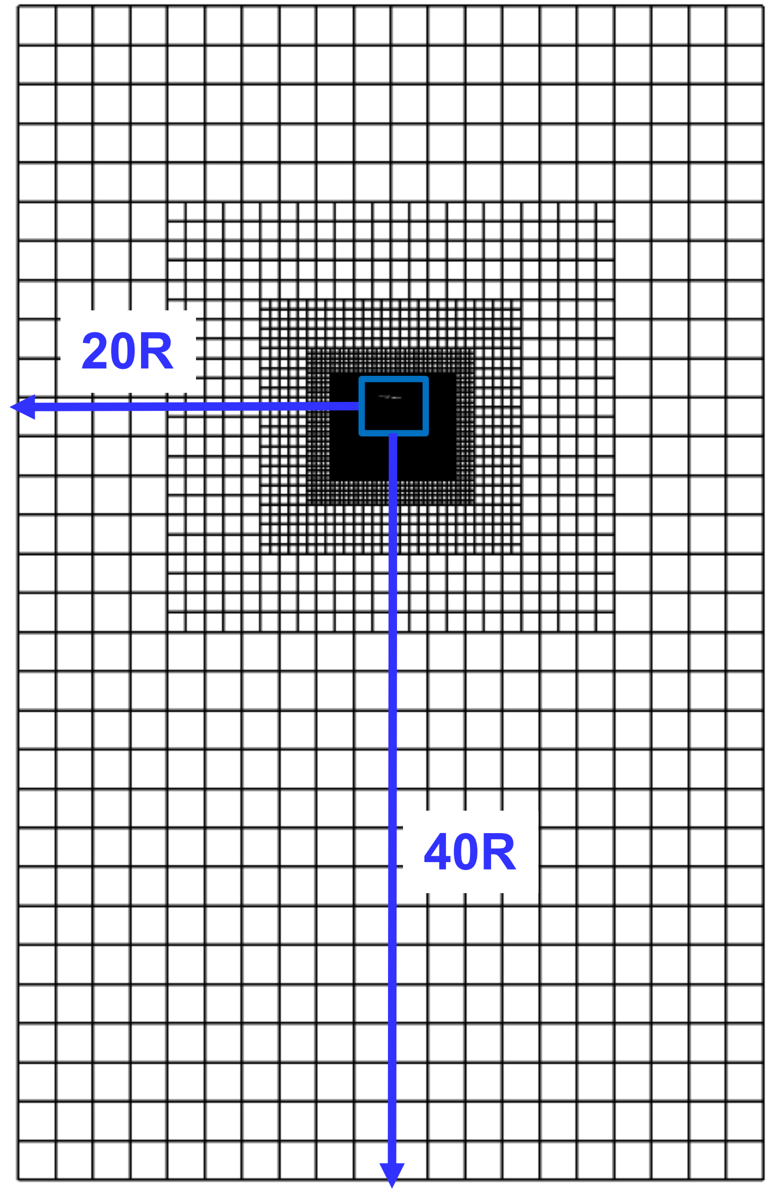
<u>Variation</u> in forces averaged over revs 6-8 and revs 8-10 < 0.25%

Off-body Solution

- **Off-body Cartesian**
  - 9 levels, finest Δx = 0.07 chord
  - Extents: 40R in wake, 20R in all other directions
  - Adaptive Mesh Refinement applied to vorticity 3R below rotor
  - Implicit BDF2 time integration, 20 sub-iterations
  - SA with rotation correction (RC) or kω SST turb model
  - *Same off-body setup for all near-body solvers*



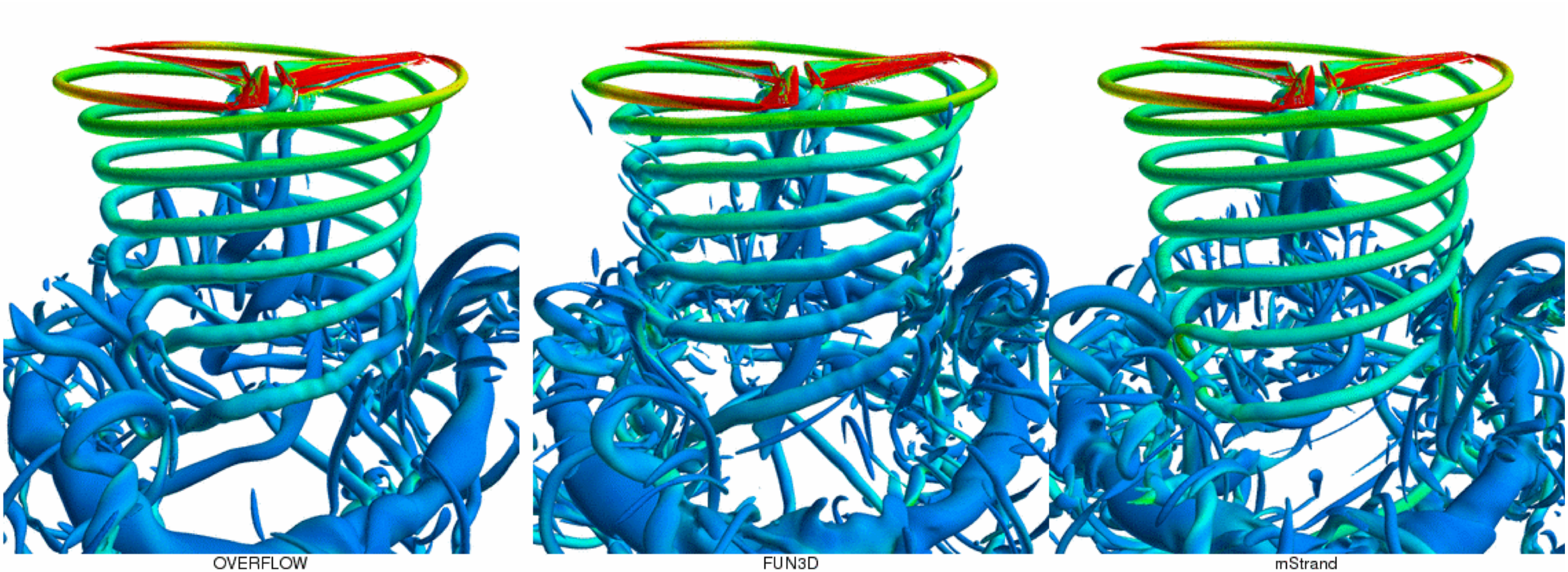
~115M off-body gridpoints



Helios JVX Calculation

Isolated Rotor

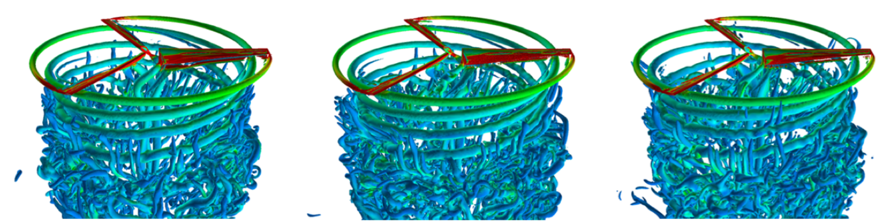
OVERFLOW	**FUN3D**	**mStrand**
Near-body	Near-body	Near-body



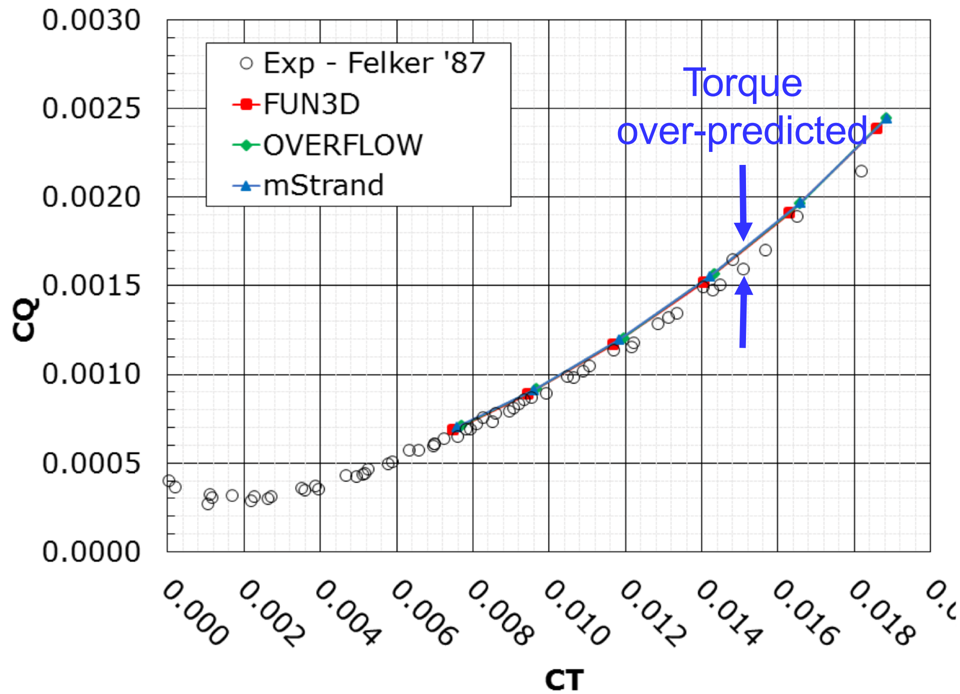
5-10 revs

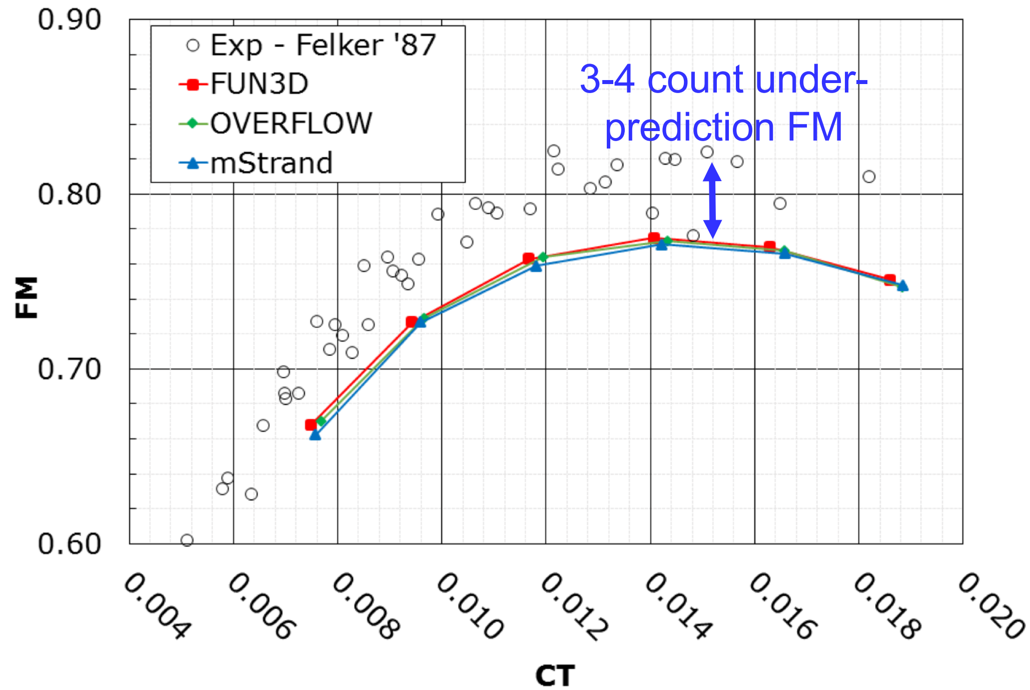
Helios JVX Results

Isolated Rotor



- **Comparable results between solvers**
  - Results using SA-RC turbulence model

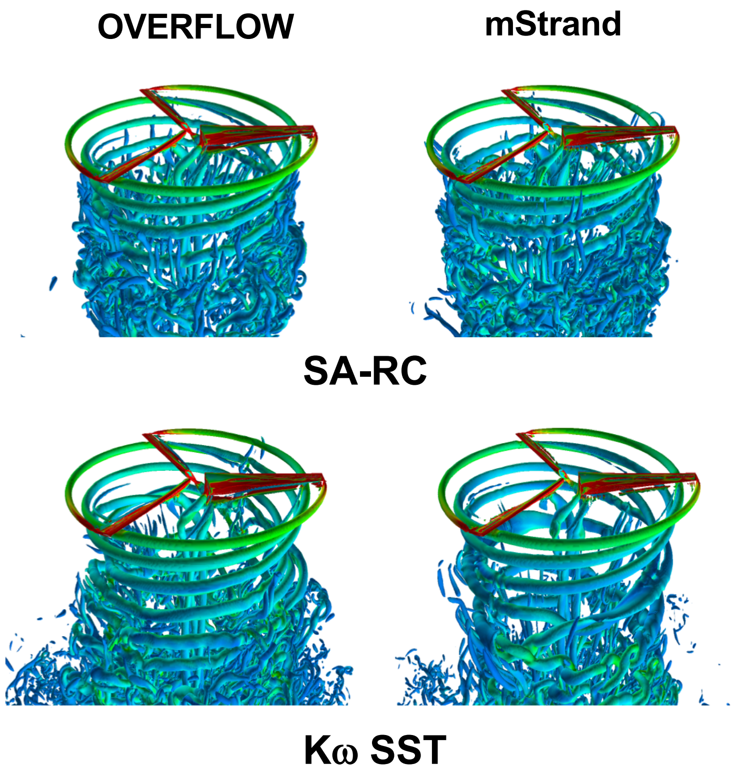


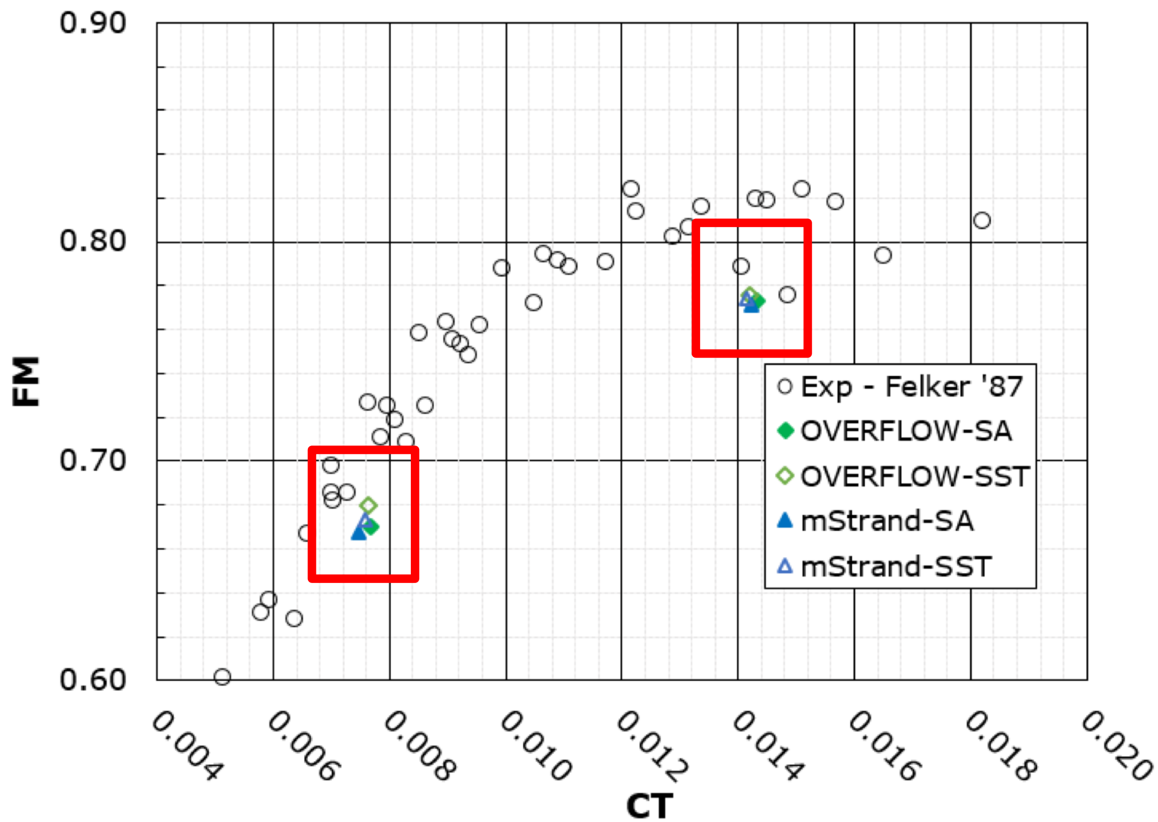


- **Future improvements**
  - Finer off-body mesh may increase FM 1-2 cts; Lakshminaryan et al, AIAA-2017-1672
  - Transition model may increase FM 1-2 cts; Potsdam & Strawn AHS J 2005

Kω SST Turbulence Model

- **Little difference between turbulence models**
  - SA-RC and kω SST FM prediction nearly identical
  - Difference smaller than test variation

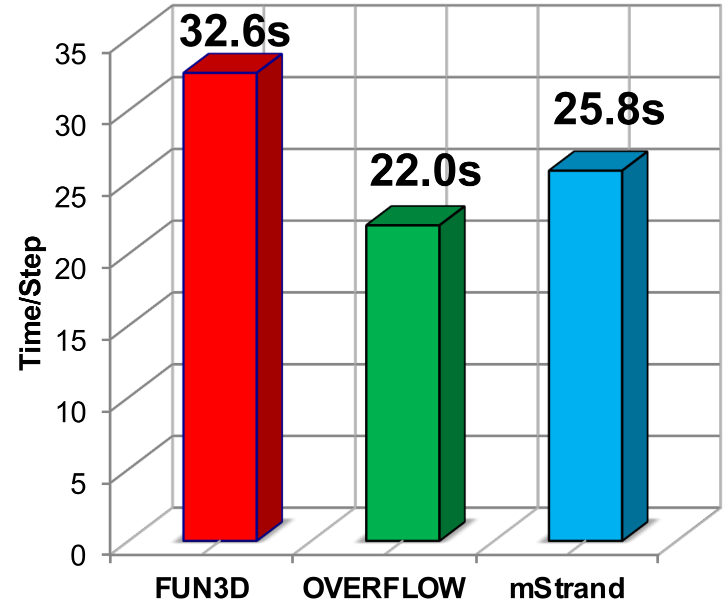




Computational Performance

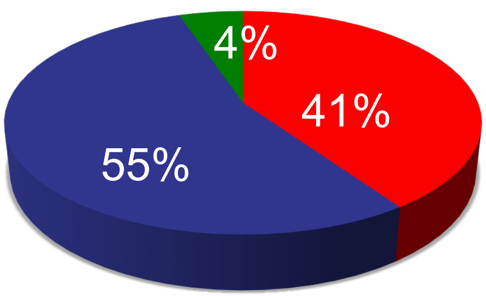
Isolated Rotor

- **HPCMP "Gordon" Cray XC40**
  - Nodes are 32-core Intel Haswell processors
  - All cases run on 20 nodes – 640 cores

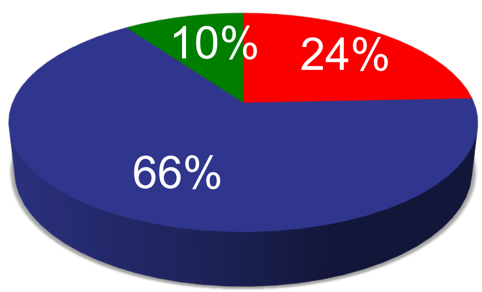


Off-body (Cartesian)
Near-body
Domain Conn/Other

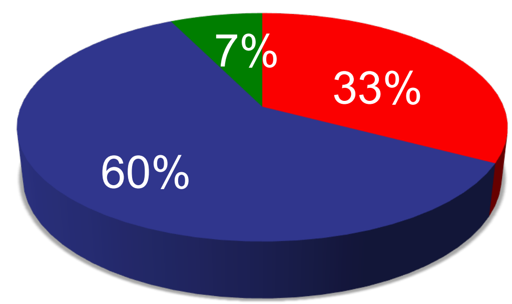
FUN3D



OVERFLOW



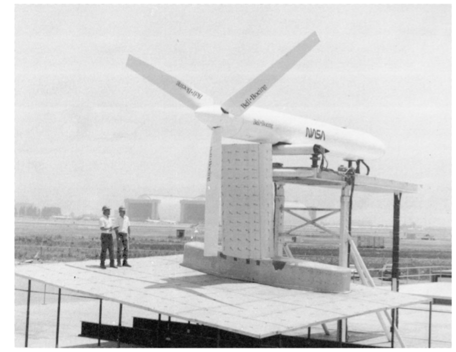
mStrand



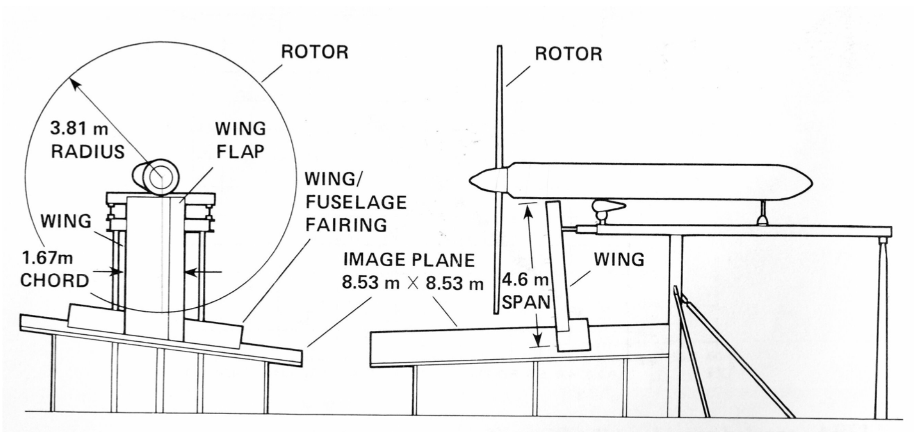
FUN3D		OVERFLOW	mStrand
130 hrs	Total Time 10 revs	**88 hrs**	**103 hrs**

Computational Setup

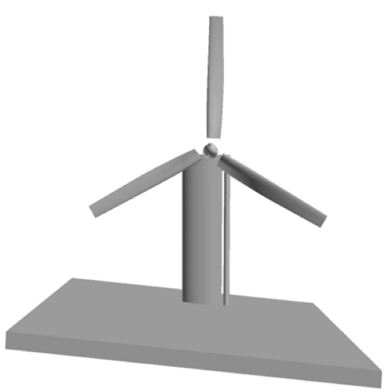
Combined configuration

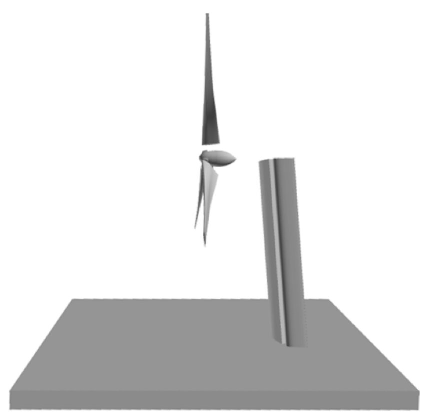


- **Two grid configurations tested**
  1. OVERFLOW rotor + FUN3D wing/flap/image plane
  2. mStrand rotor + mStrand wing/flap/image plane
- **Automatic settings used for strand meshing**

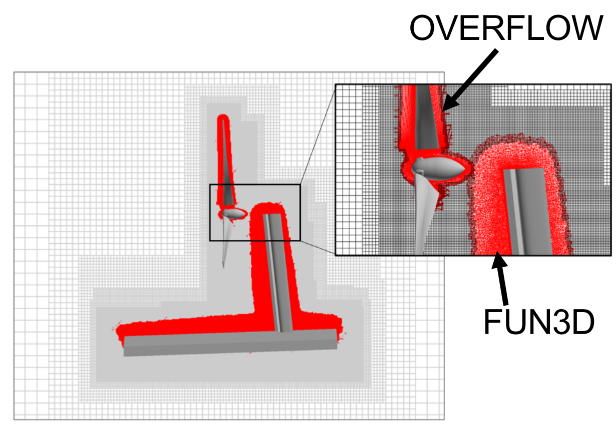


Courtesy Felker et al, '87

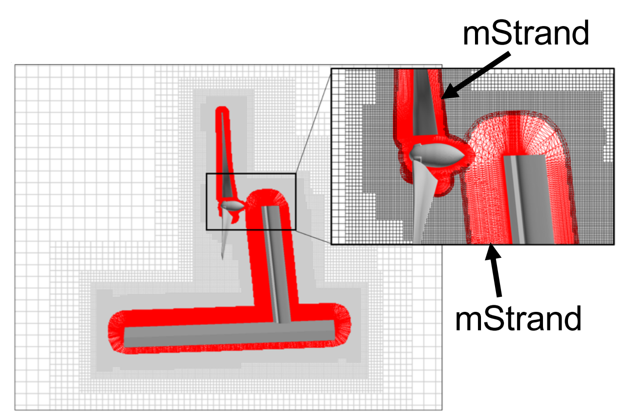




Config 1
FUN3D-OVERFLOW



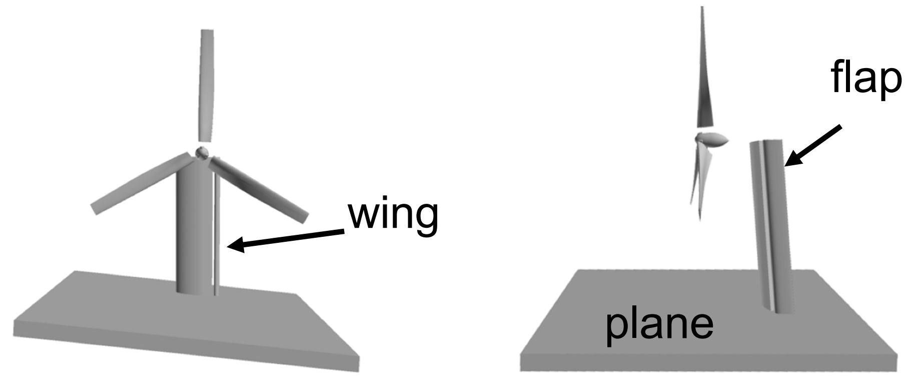
Config 2
mStrand



Mesh and Solver Settings

Combined Configuration

- **Computational conditions**
  - Same settings as isolated rotor
  - SA-RC turb model
- **Ran two thrust conditions**
  - Low thrust: Coll = 6°
  - High thrust: Coll = 12°



Wing span	4.75m
Wing chord	1.76m
Flap chord ratio	0.31
Flap angle	67 deg
Plane dims	8.53m square

Wing/Flap/Image Plane Mesh Stats

Gridpoints	**Hub**		**Wing/Flap/Img plane**	
	Surface	Volume	Surface	Volume
Unstructured FUN3D	5K	0.2M	232K	15.0M
Strand mStrand	5K	*0.2M	232K	*11.6M

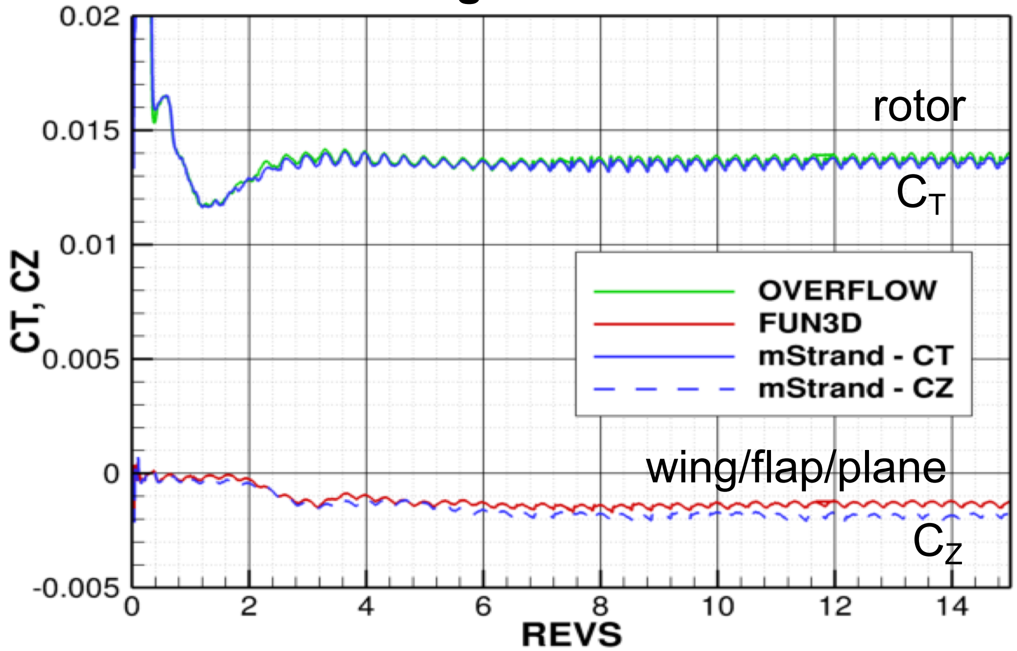
*Strand meshes constructed automatically using default settings

Convergence & Force Reporting

Combined Configuration

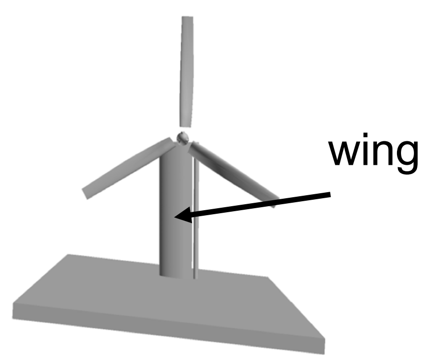
- **Ran download cases for 15 revs**
- **Greater variation in download (C_Z) than Figure of Merit in isolated rotor calculations**
  - Low thrust (6 deg) – 4.6%-5.1%
  - High thrust (12 deg) – 0.2%-0.4%

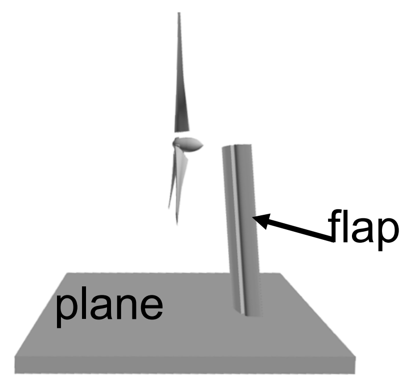
Convergence over 15 revs



Component download contribution

Component	C_Z	%
hub	-0.223e-5	0.2%
plane	0.571e-5	-0.5%
wing	-0.1443e-2	119.1%
flap	0.2227e-3	-18.3%
total	-0.1212e-2	100%





Reported download C_Z is wing/flap/plane combination

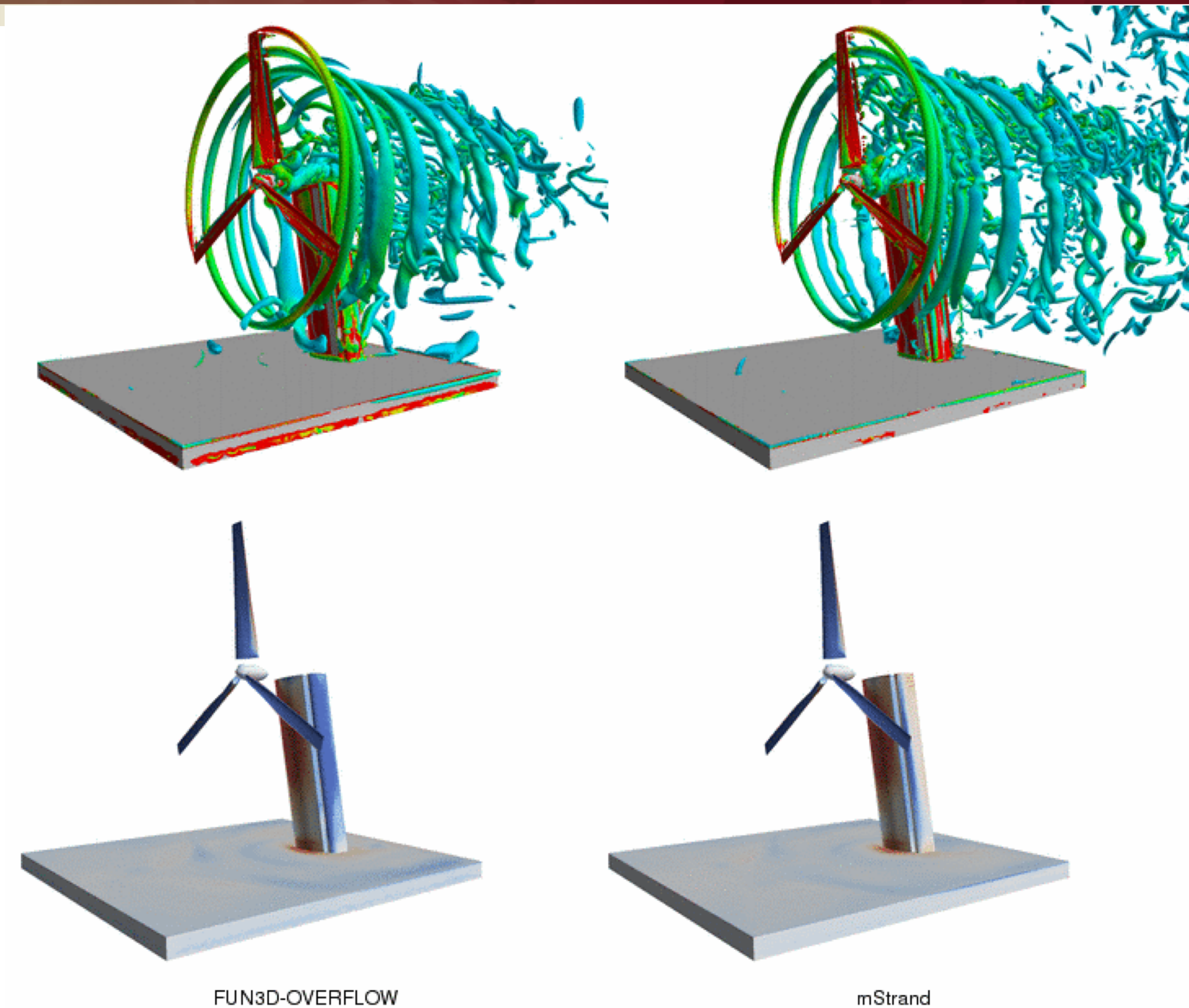
Helios JVX Calculation

Rotor + Wing/Flap/Image Plane

θ = 12°
10-15 revs

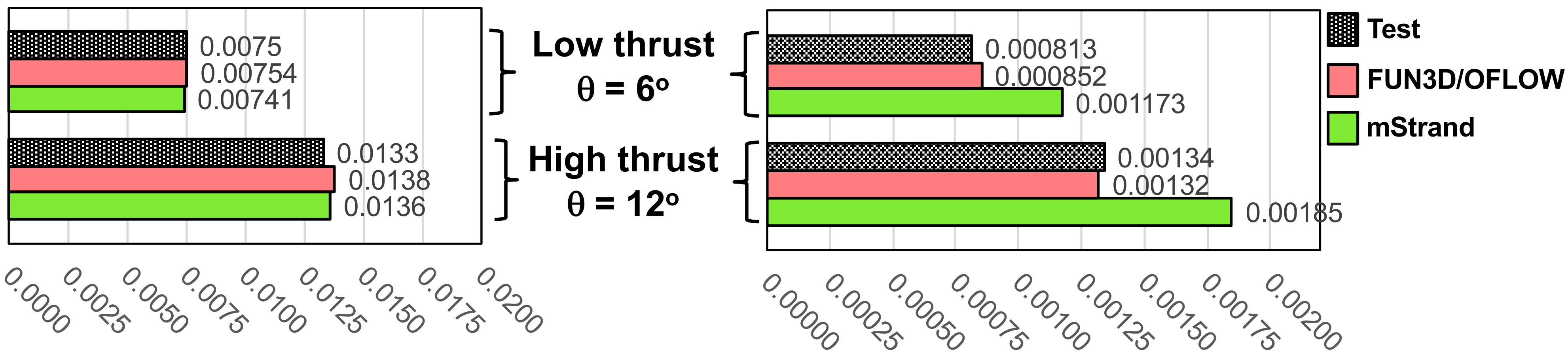
Iso-surf of Q_{crit} colored by vorticity

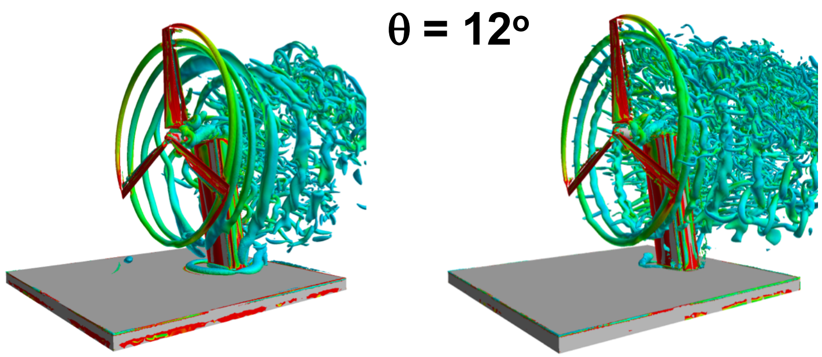
Surface C_p



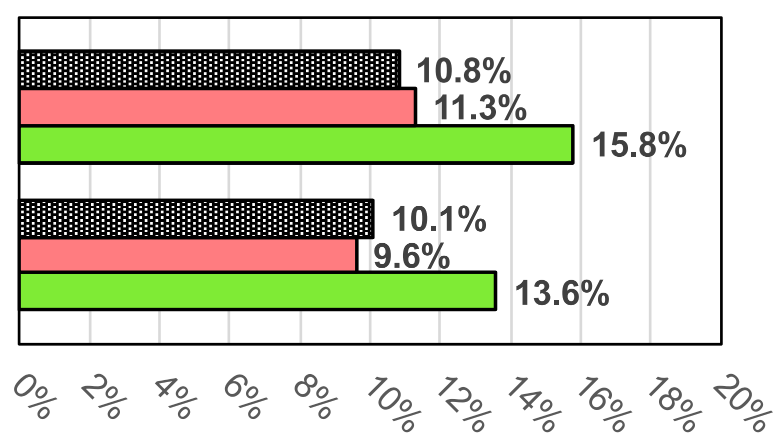
JVX Combined Computed Results

15 revs (forces averaged over last two revs)





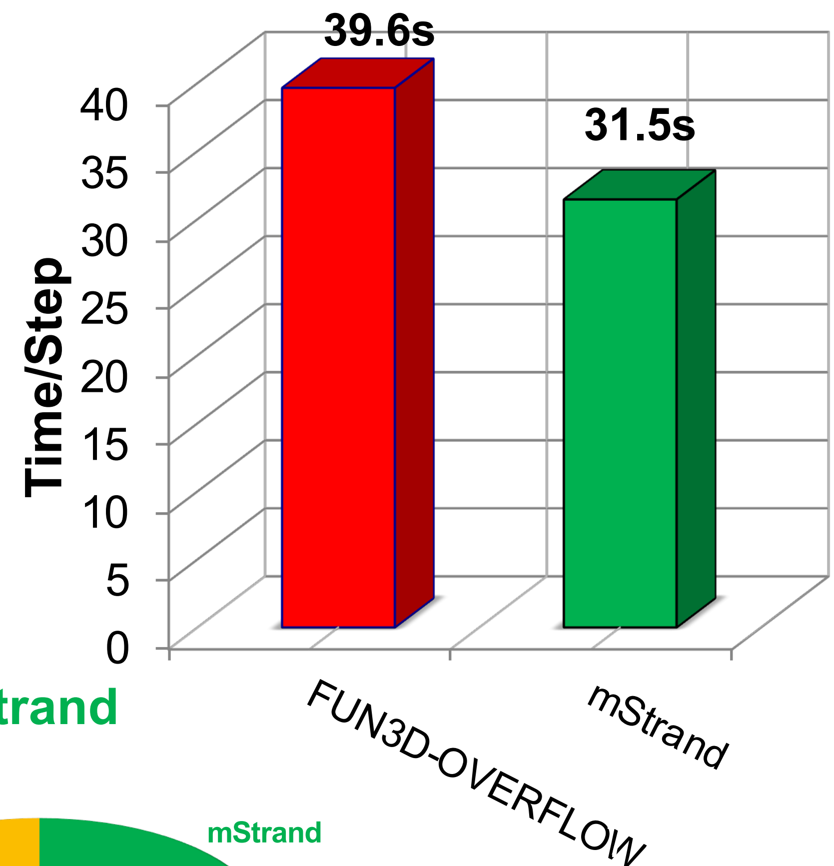
FUN3D-OVERFLOW mStrand

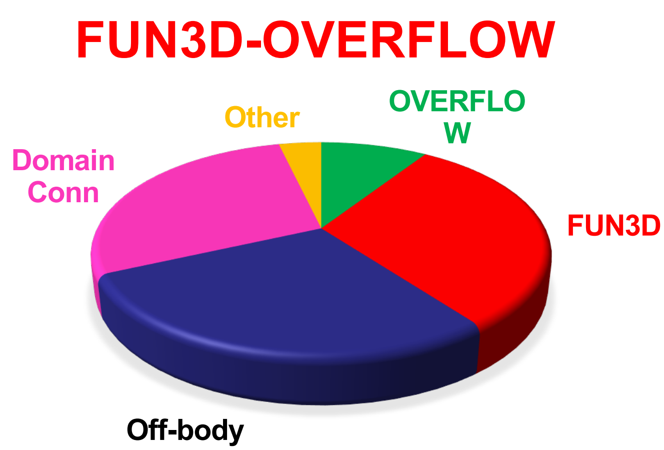


- **FUN3D-OVERFLOW result matches test data to within ±0.5%**
- **mStrand overpredicts**

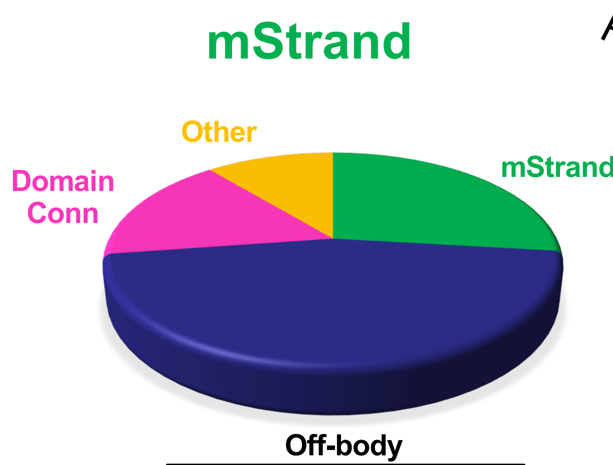
Computational Performance
Combined Rotor/Wing/Flap/Image Plane

- **HPCMP “Topaz” SGI ICE X**
  - Nodes 36-core Intel Haswell processors
  - All cases run on 30 nodes – 1080 cores





238 hrs



189 hrs

Total Time
15 revs

Concluding Remarks

- **Investigated Helios for tiltrotor download prediction**
  - Performed calculations of isolated rotor and combined wing/flap/image plane of JVX 0.658-scale model V-22
- **Isolated rotor results**
  - Tested three solvers - mStrand, FUN3D, OVERFLOW – results nearly identical
  - OVERFLOW fastest, strands 1.6X slower, FUN3D 2.5X slower
  - All solvers under-predict FM by 3-4 counts
- **Download results**
  - FUN3D/OVERFLOW and mStrand results did not match
    - FUN3D/OVERFLOW predict to ±0.5% of test
    - mStrand over-predicts 3.5%-5%
  - Differences may be due to automatic strand mesh settings
- **Future work**
  - Inclusion of transition models
  - Mesh refinement study
  - Add KCFD for unstructured solver comparison in combined configuration

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Questions?