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Politecnico di Milano
Department of Aerospace Science and Technology

QUADROTOR CYCLOGYRO AIRCRAFT IN FORWARD FLIGHT CFD MODEL

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Session: General CFD III

Session Chair: TBA

Date: June 29, 2016

- 1 Introduction
 - cycloidal rotors
 - aerial vehicle under study

- 2 CFD Model
 - code modifications
 - meshes
 - aircraft mesh
 - running parallel

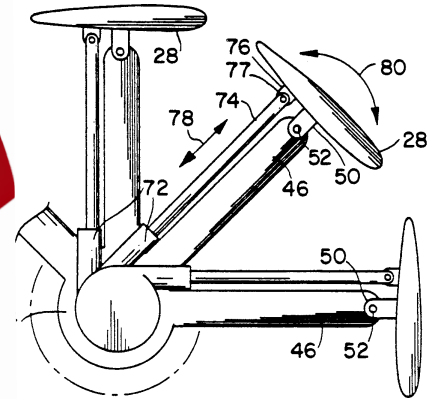
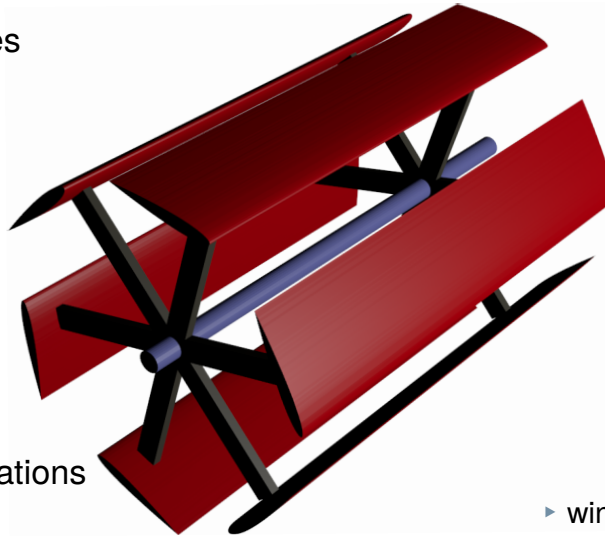
- 3 Validation
 - rotor
 - full aircraft

- 4 Conclusion

- 5 Ongoing Activities

- Aeronautic capabilities

- ▶ hover
- ▶ 360° thrust vectoring
- ▶ high advance ratio
- ▶ rapid vector changes



- Contemporary applications

- ▶ tugboats



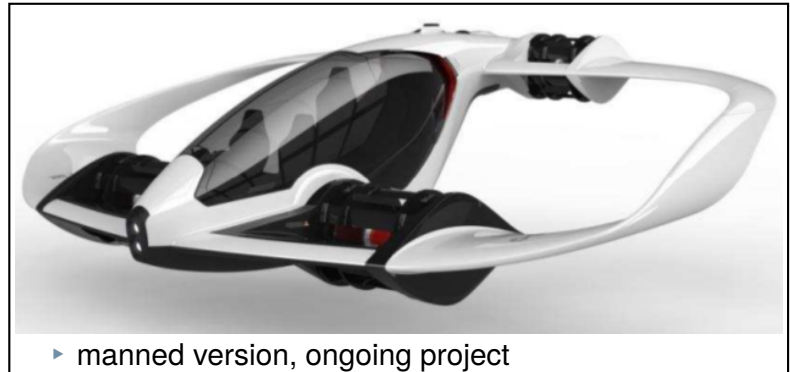
- ▶ wind turbines



- Aerial vehicle tested: IAT21's D-Dalus L1

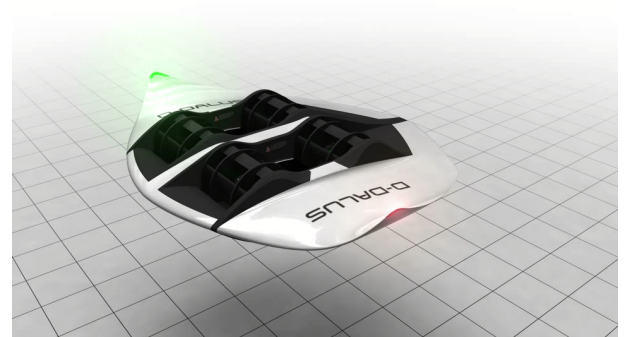


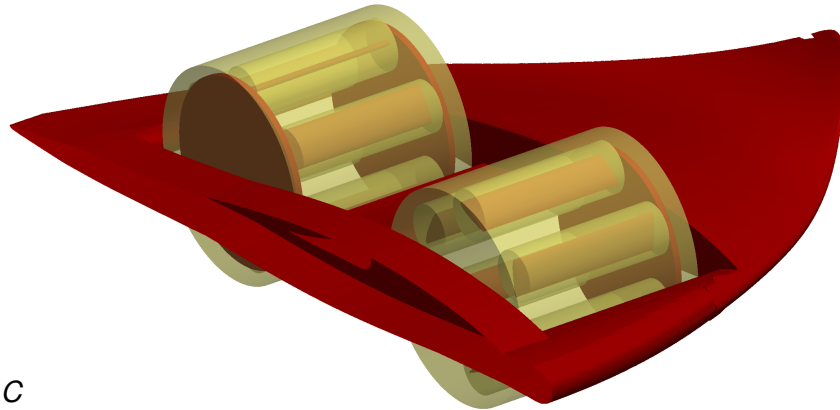
▶ unmanned prototype, CFD tested



▶ manned version, ongoing project

- CFD objective: rotor interaction
 - ▶ rotor model
 - 12 cm and 60 cm radii
 - ▶ airframe model
 - 12 cm radius
 - ▶ experimental lookalike
 - 12 cm radius
 - proof of concept at 30 m/s and 15°
- All models **3D pimpleDyMFoam** w/o viscosity





- **Embed rotating interface**

- ▶ based on *oscillatingRotatingMotion.C*

- septernion TR(septernion(**calcOrigin_**)*R*septernion(-**calcOrigin_**));
- vector calcOrigin_ = outterOrigin_ + outterRadius_ * vector (sign(outterOmega_)*cos(fabs(outterOmega_)*t + outterInitialOffset_*pi), sin(fabs(outterOmega_)*t + outterInitialOffset_*pi), 0);
- vector eulerAngles = amplitude_ * sign(omega_) * (sin(fabs(omega_)*t) + initialOffset_*pi) - sin(initialOffset_*pi);

- ▶ available here: www.cfd-online.com/Forums/openfoam-solving/124586-dynamic-mesh-within-dynamic-mesh.html

- **Moving wall slip boundary condition**

- ▶ based on *movingWallVelocityFvPatchVectorField.C*

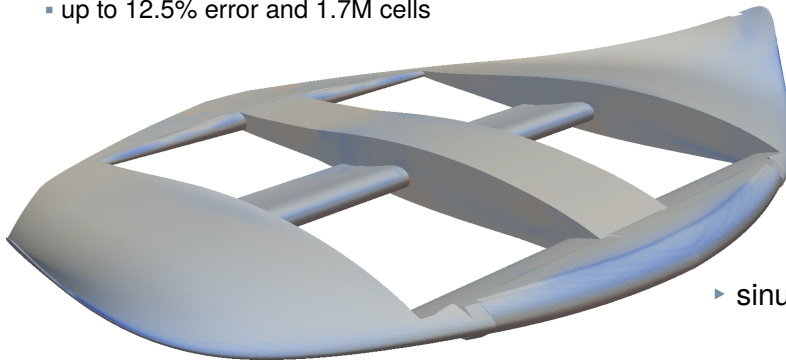
- vectorField::operator=(**nHat*(nHat & (Up + n*(Un - (n & Up)))) + transform(I - sqr(nHat), this->patchInternalField())**);

- ▶ available here: www.cfd-online.com/Forums/openfoam-solving/105274-free-slip-moving-wall-bc.html#post509989

- Tool: *snappyHexMesh*

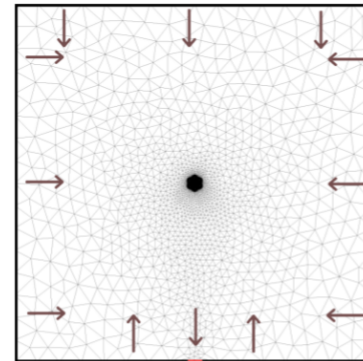
- Airframe

- tests at 15° angle of attack
 - separation is a challenge
 - ◆ *slows/impedes convergence*
 - up to 12.5% error and 1.7M cells



- Rotor

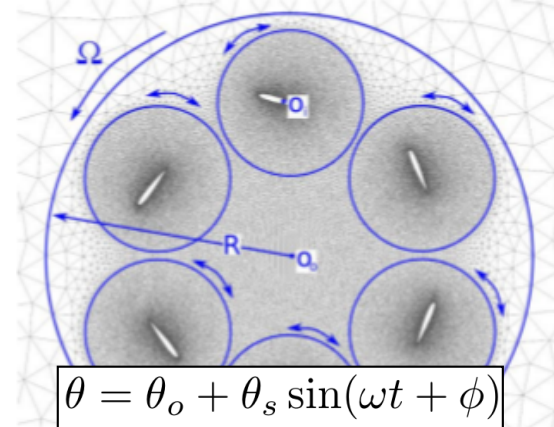
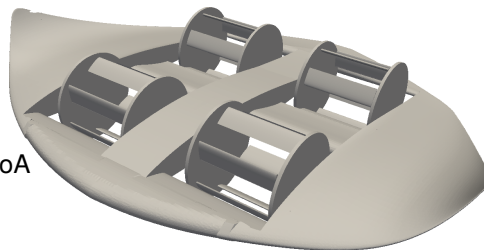
- with embed AMI interface
- boundary vel. from momentum theory



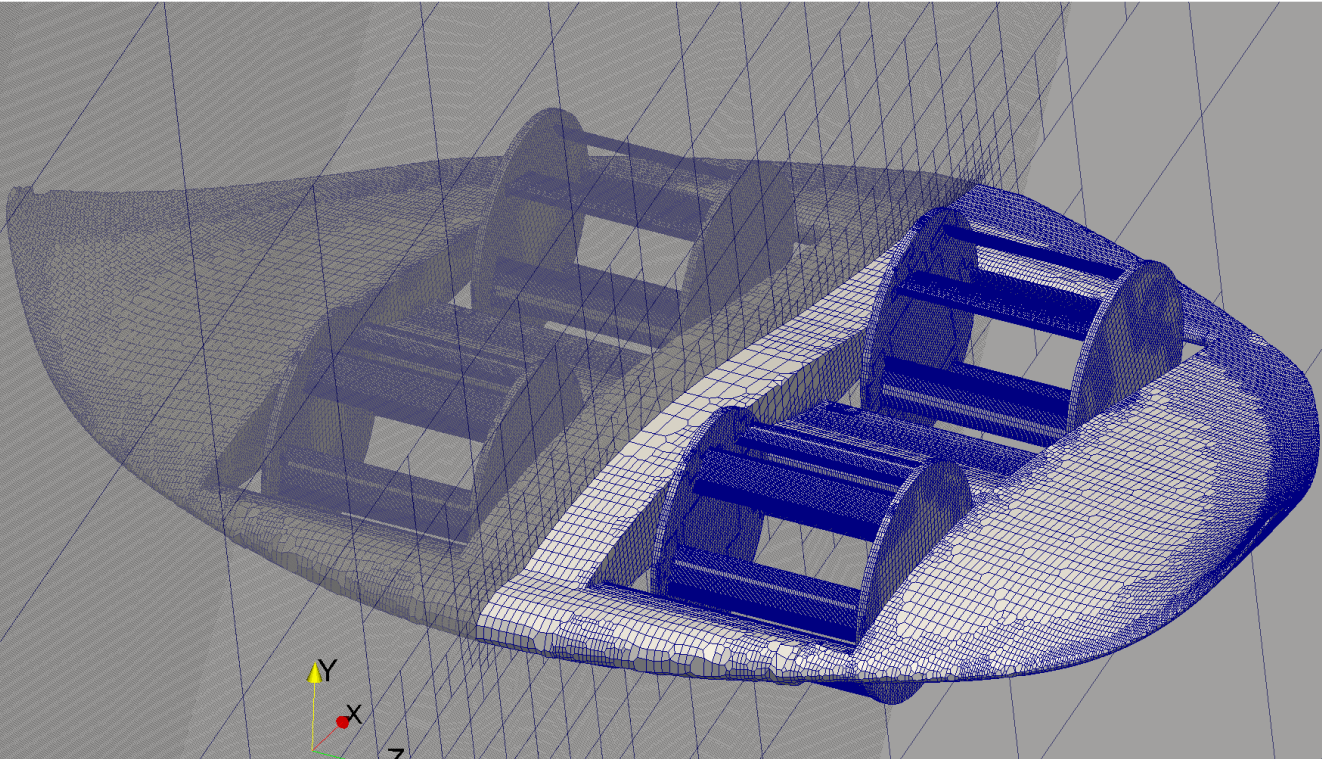
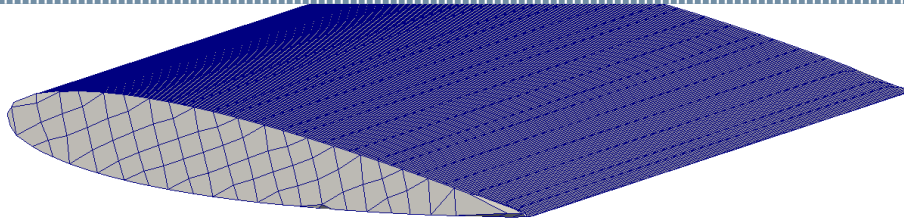
- sinusoidal pitching, fixed offset, and phase angle

- Aircraft

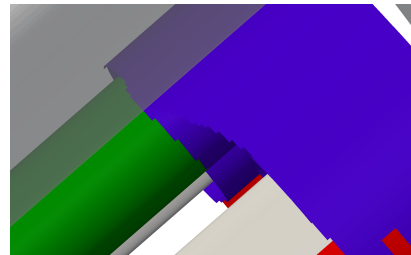
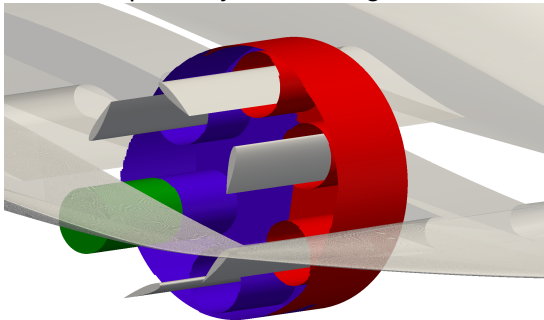
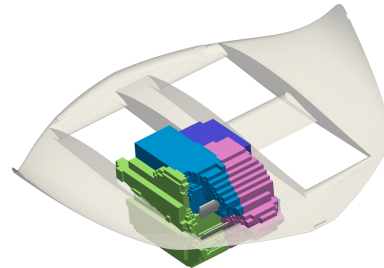
- airframe, blades, endplates
- symmetric front and rear rotations
- lateral symmetry
- boundary conditions
 - inlet
 - ◆ zeroGradient pressure
 - ◆ fixedValue velocity w/ AoA
 - outlet
 - ◆ fixedValue 0 pressure
 - ◆ inletOutlet 0 0 velocity



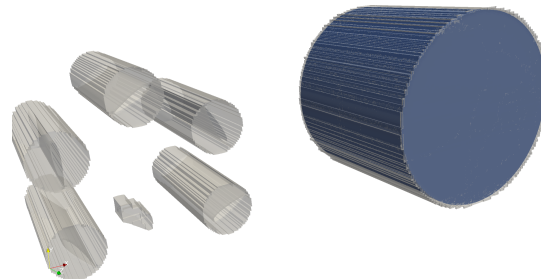
$$\theta = \theta_o + \theta_s \sin(\omega t + \phi)$$



- Meshing in parallel
 - ▶ exhaustive initial setup
 - ▶ improves meshing speed
- Solving in parallel
 - ▶ simple initial setup
 - ▶ possibly misleading

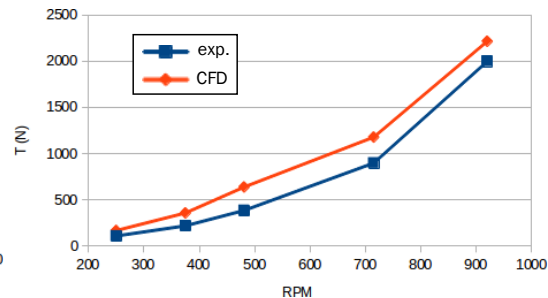
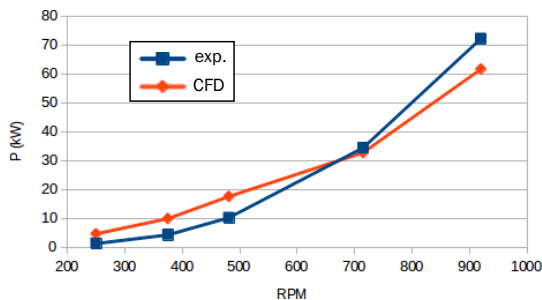


- Decomposition
 - ▶ 3.6M cells
 - ▶ preserveFaceZones
 - ▶ preservePatches
 - ▶ **singleProcessorFaceSets** →
 - ▶ **simple decomp.** retained, up to 4 procs.

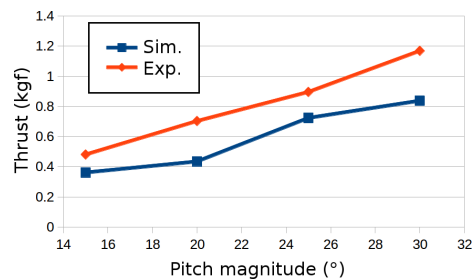
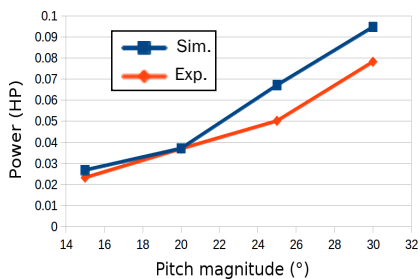
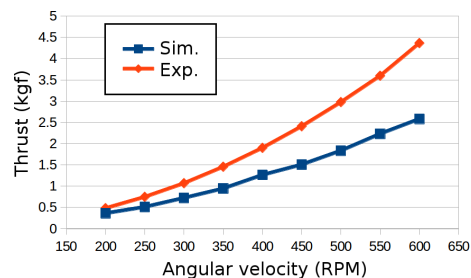
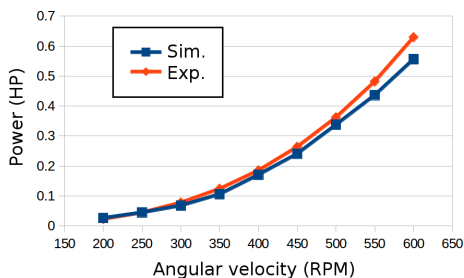


• 3D CFD thrust and power

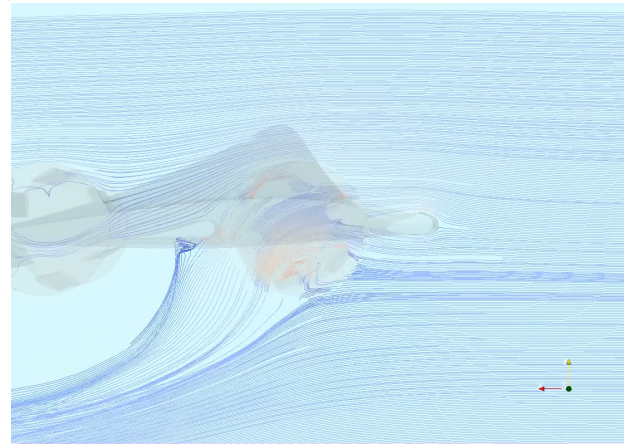
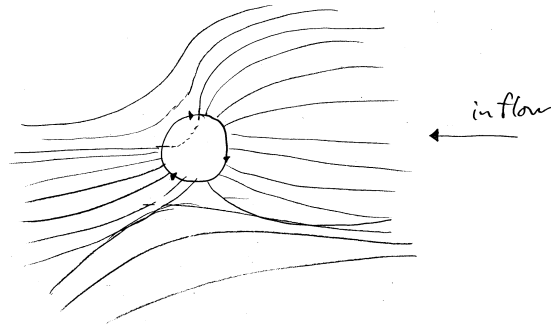
- ▶ IAT21 D-Dalus L3
 - [250, 900] rpm
 - ▶ + qualitative match



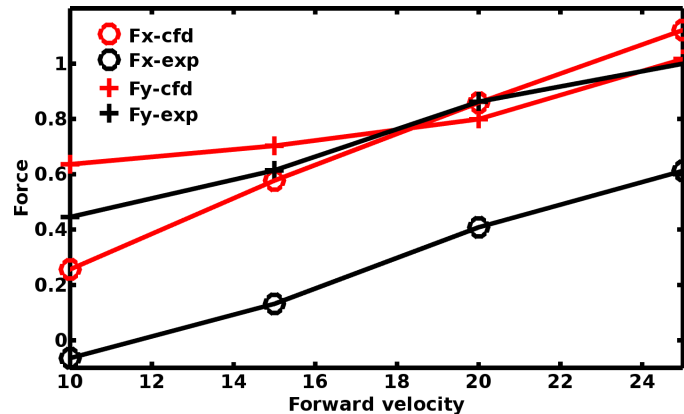
- ▶ Yun et al. baseline case
 - [200, 600] rpm
 - [15°, 30°] pitch magnitudes
 - ▶ + qualitative match



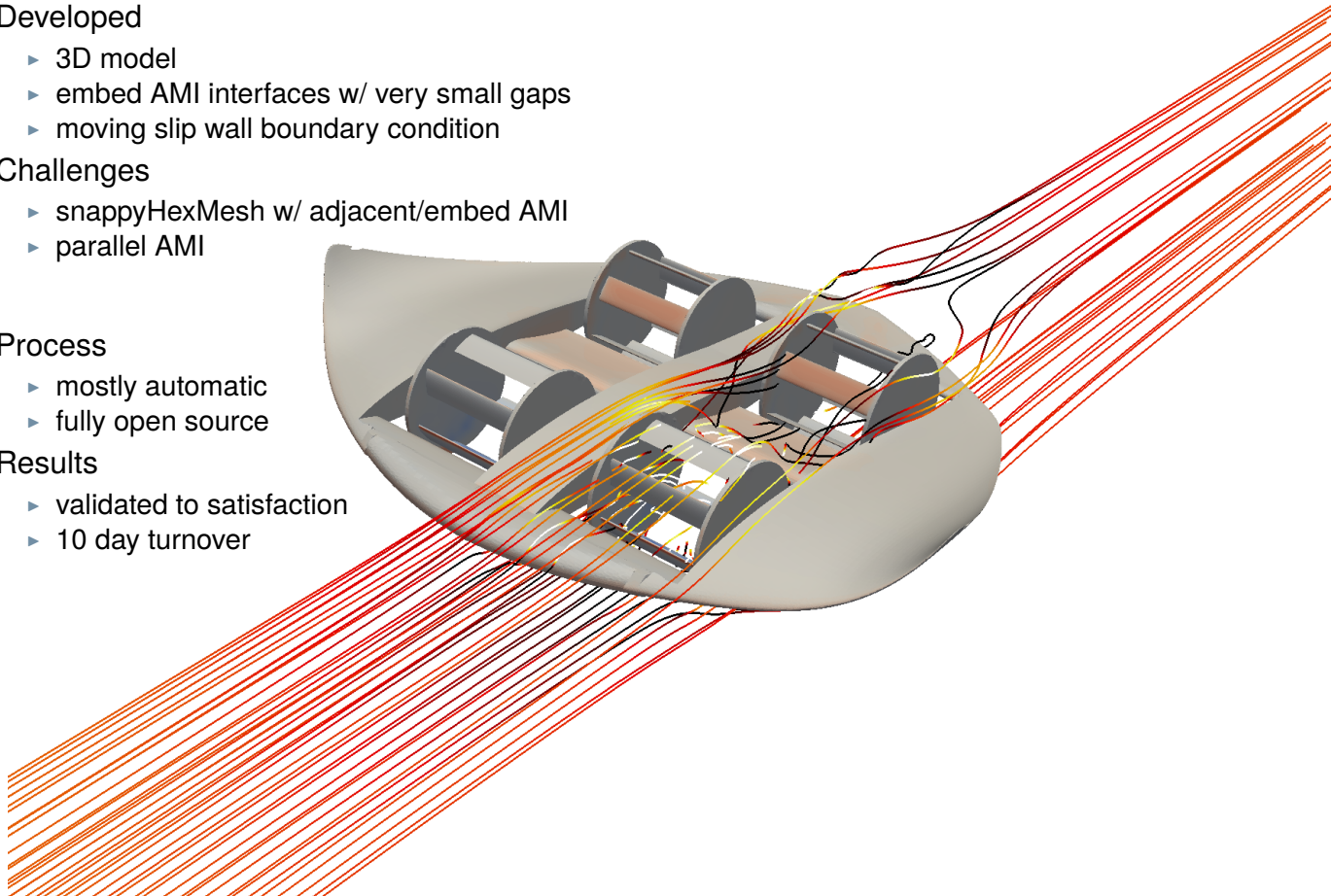
- Flow in forward flight



- Difficulty from unpowered rear rotor
 - ▶ tested with rear rotor blade vels. btwn. [-12.5,25] m/s
 - correspond to *full*, *half*, *null*, and *neg. half* stream velocities
 - retained stationary rear rotor
 - ▶ attempted 2x refined mesh
 - computation time 1 day → 22 days
- Trend match at various airspeeds
 - ▶ 10 m/s, 15 m/s, 20 m/s, and 25 m/s



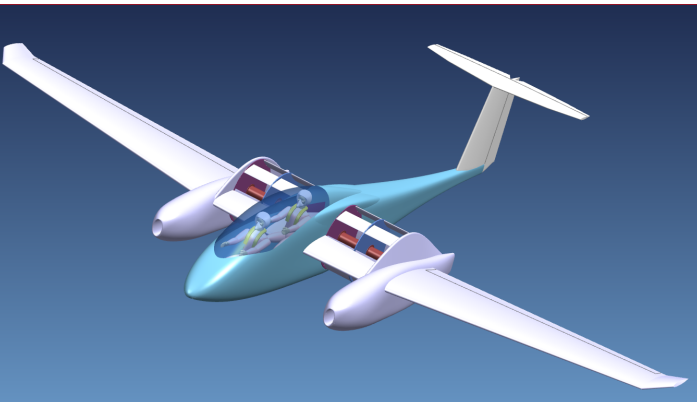
- Developed
 - ▶ 3D model
 - ▶ embed AMI interfaces w/ very small gaps
 - ▶ moving slip wall boundary condition
- Challenges
 - ▶ snappyHexMesh w/ adjacent/embed AMI
 - ▶ parallel AMI
- Process
 - ▶ mostly automatic
 - ▶ fully open source
- Results
 - ▶ validated to satisfaction
 - ▶ 10 day turnover



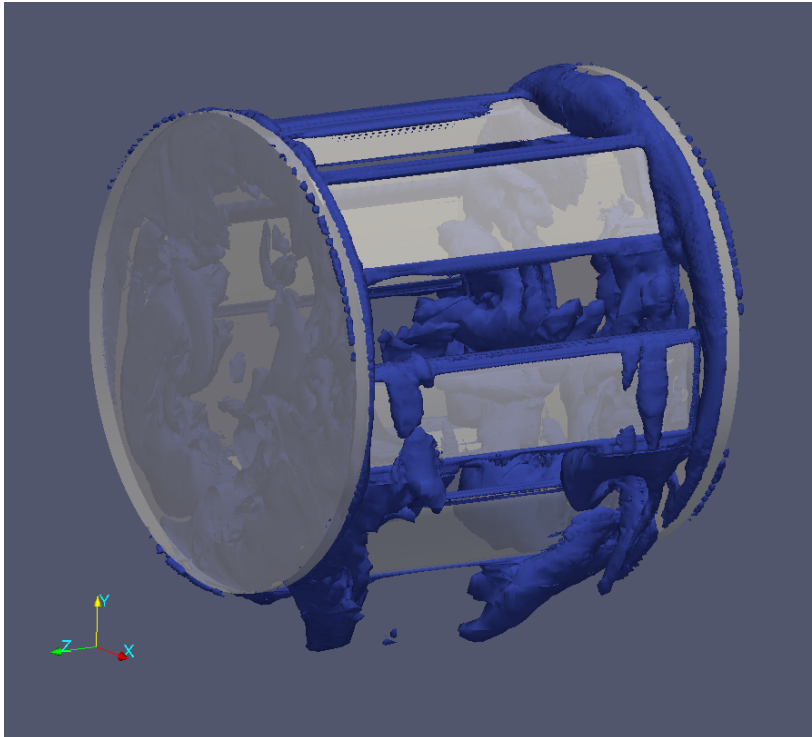
- Article on model development
- Multibody and CFD models in progress
 - ▶ Heligyro
 - 3D
 - actuator disk main rotor
 - rotor interaction
 - ▶ Cyclowing
 - 2D
 - parametric study



- ▶ Cyclomobile
 - efficiency study



Thank you for your kind attention



Questions, comments, and suggestions are welcome