

Rotor5: Rotor design under 5 hours
using ultra-fast and high-fidelity CFD simulation
and automatic meshing



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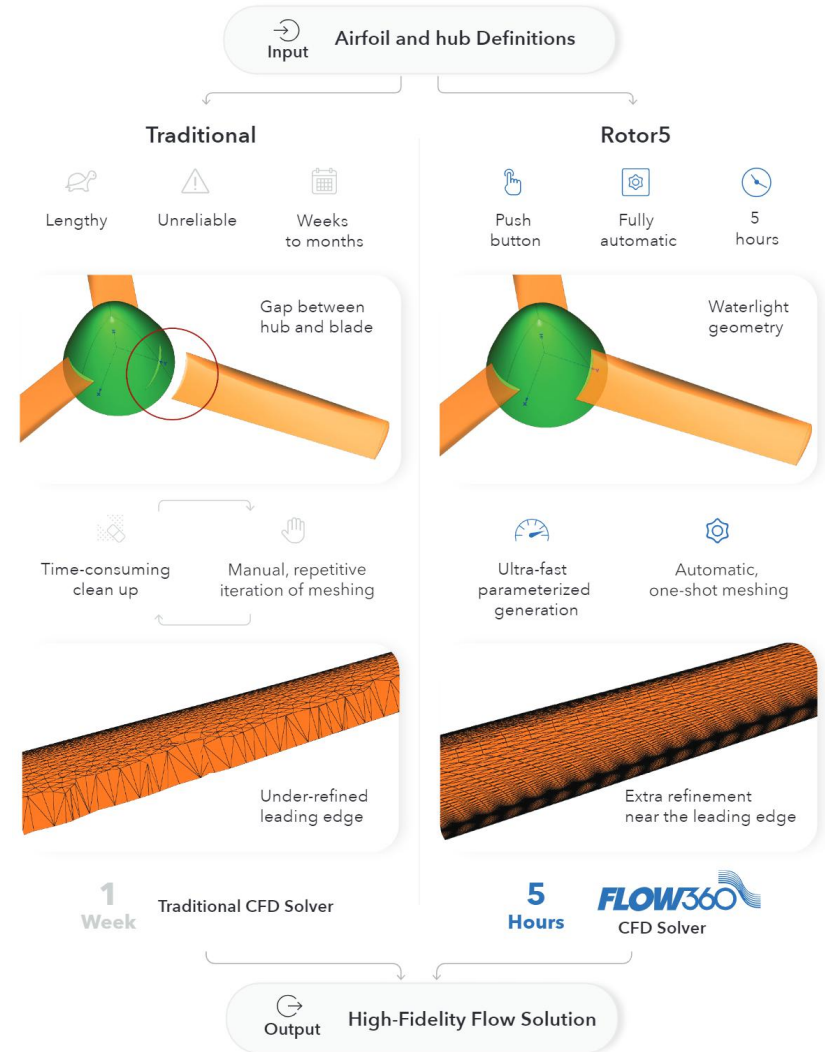
Introduction

Advantages

1. Watertight geometry
2. Splitting (but not over-splitting) the patches
3. Auto labeling: patches and edges
4. Auto meshing (surface and volume)

Different resolutions for different patches

Anisotropic layers near given edges





XV-15 Rotor

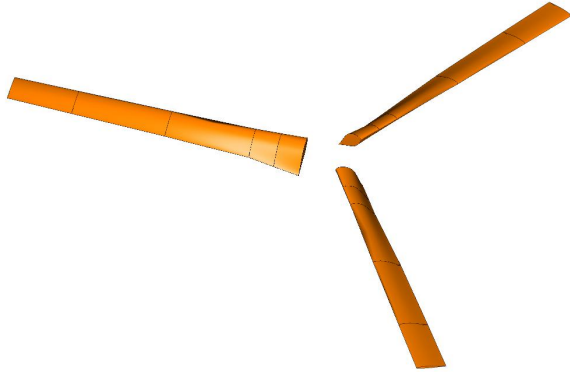


Table 1 Main properties

Parameter	Value
Number of blades, N_b	3
Rotor radius, R	150 inches
Reference blade chord, c_{ref}	14 inches
Aspect ratio, R/c_{ref}	10.71
Rotor solidity, σ	0.089
Linear twist angle, Θ	-40.25°

Felker, F and et. al. 1986

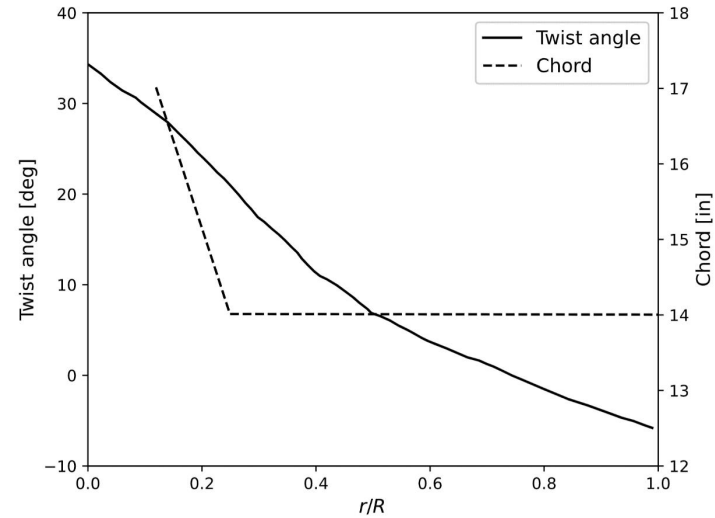


Table 2 Airfoil definitions

r/R	Airfoil
0.09	NACA 64-935
0.17	NACA 64-528
0.51	NACA 64-118
0.80	NACA 64-(1.5)12
1.00	NACA 64-208



Freestream Conditions

<https://www.nasa.gov/centers/dryden/multimedia/imagegallery/XV-15/ECN-13850.html>

<https://gallery.vtol.org/image/Gltac>

	Airplane Mode	Hover Mode
Blade-tip Mach number (M_{tip})	0.54	0.69
Reynolds number (Re)	4.50×10^6	4.95×10^6
Blade pitch angle (θ_{75})	26°, 27°, 28°, 28.8°	0°, 3°, 5°, 10°, 13°
Angle of attack (α)	-90°	
Advance ratio	0.337	



Airplane mode



Helicopter mode



Figure of Merit (FoM)

Maisel, M. D and et. al 2000

Empty weight

$$W_{\text{empty}} = 4,574 \text{ kg}$$

Maximum gross weight

$$W_{\text{gross}} = 6,000 \text{ kg}$$

Take $g = 9.8 \text{ m/s}^2$, thrust from each rotor:

$$T = \frac{1}{2} g W$$

Thrust coefficient

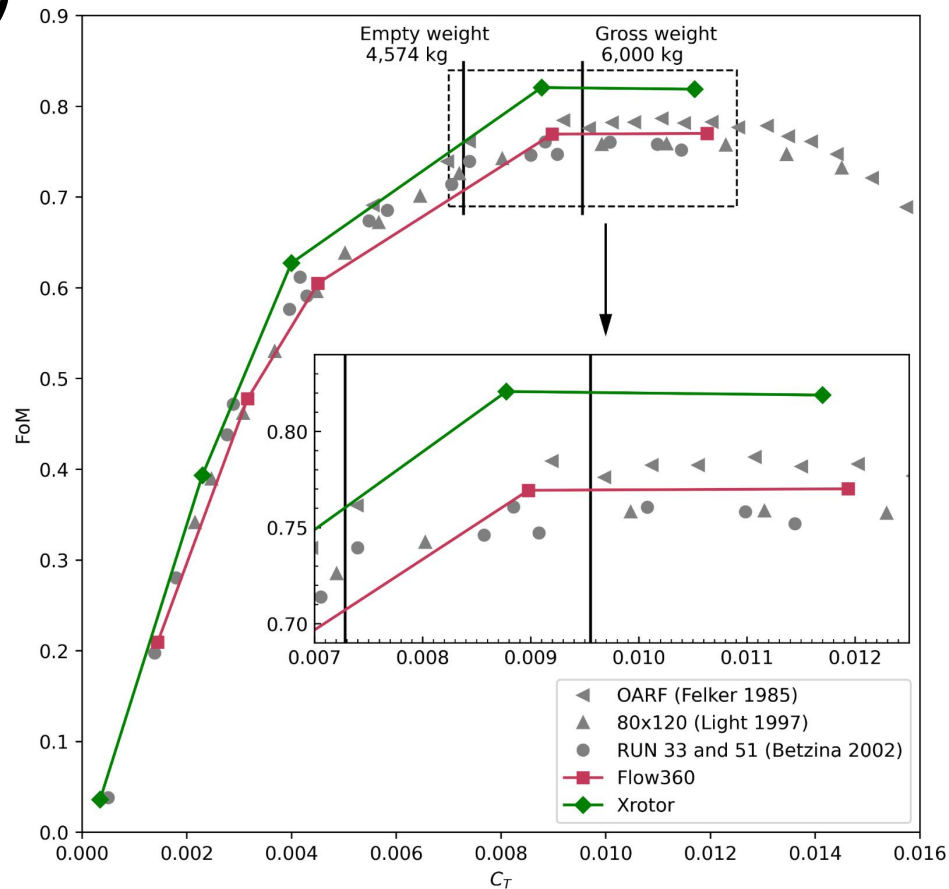
$$C_T = \frac{T}{\rho (\Omega R)^2 A}$$

Torque coefficient

$$C_Q = \frac{Q}{\rho (\Omega R)^2 A R}$$

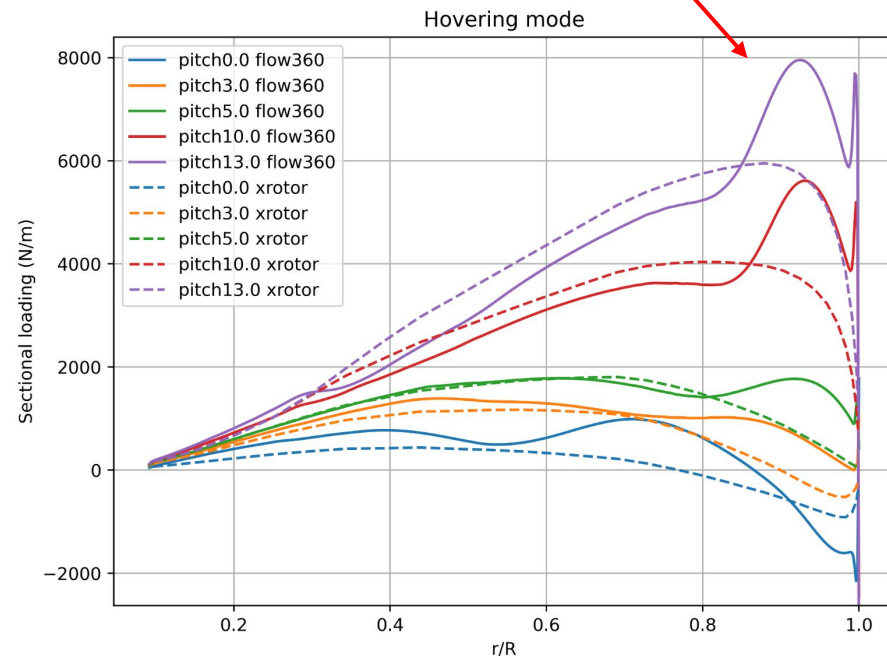
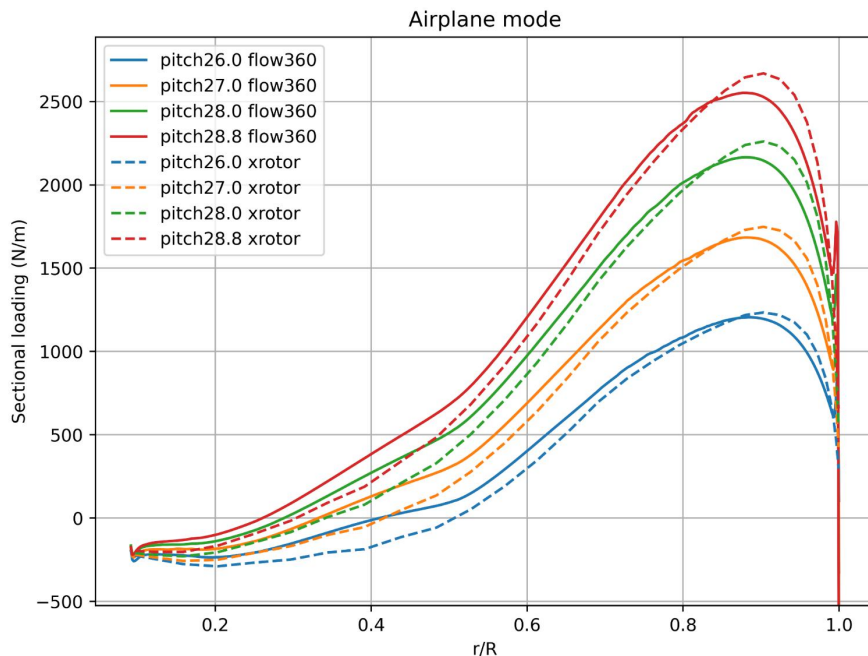
Figure of Merit

$$\text{FoM} = \frac{C_T^{3/2}}{\sqrt{2} C_Q}$$





Sectional Loading



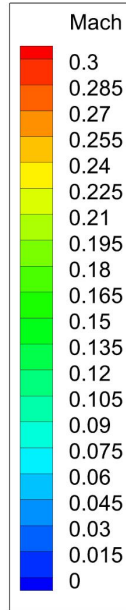
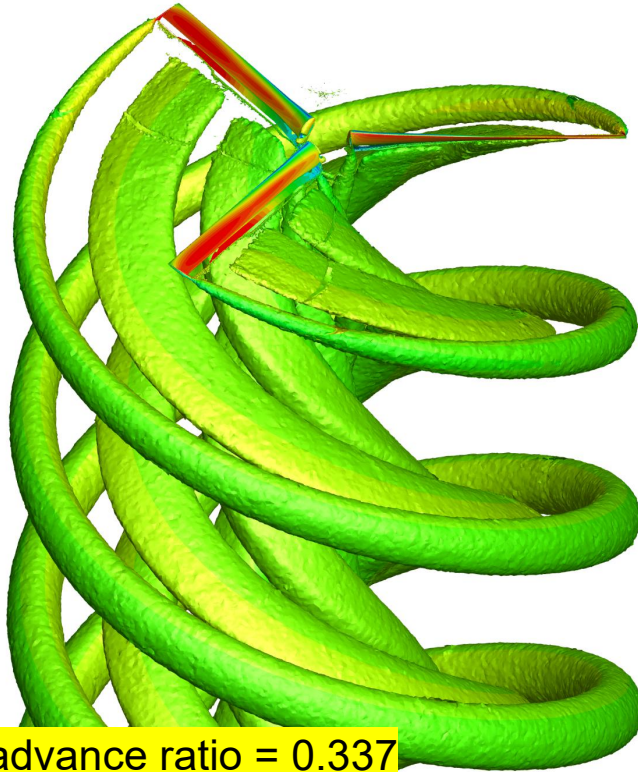
Different colors: different blade pitching angles.
Solid and dashed lines: Flow360 and Xrotor results.



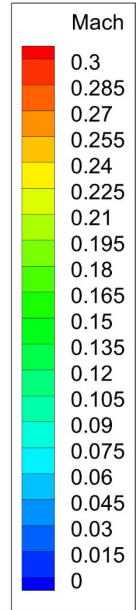
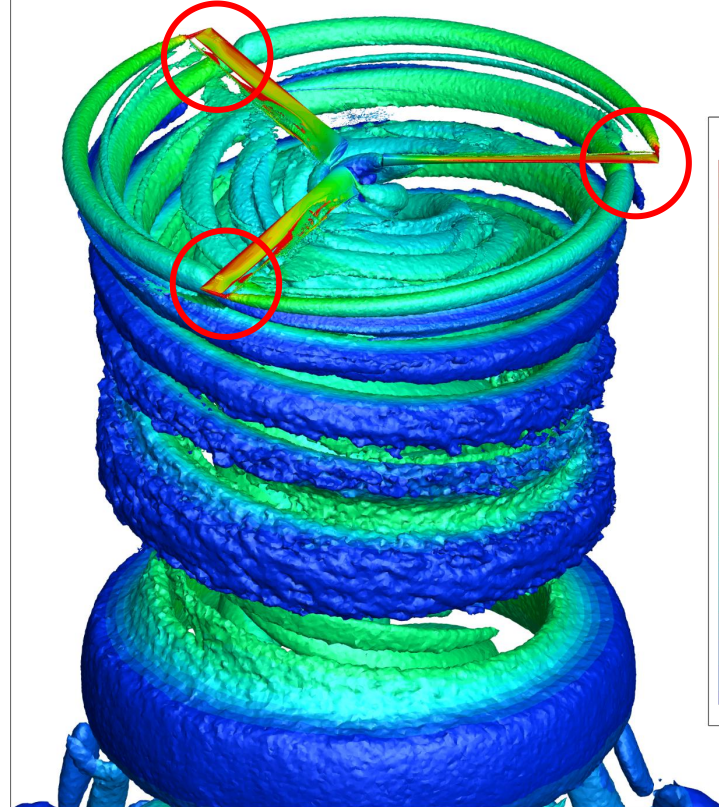
Q-Criterion Isosurface

Blade-vortex interaction creates induced drag near the tip and further increases the torque

Airplane mode, pitch angle = 28.8 deg



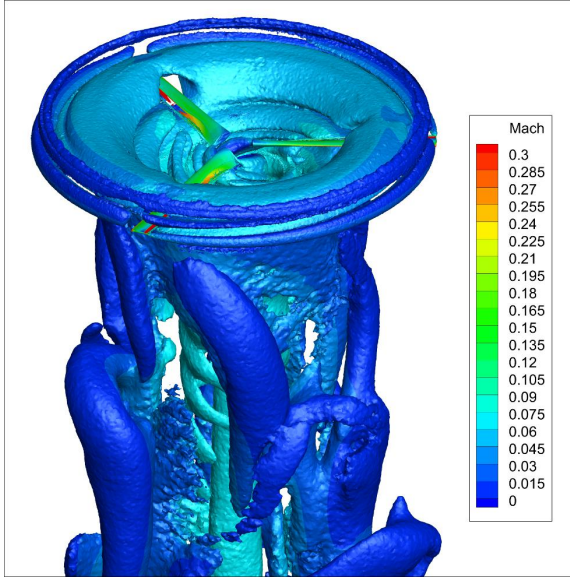
Hover mode, pitch angle = 13 deg



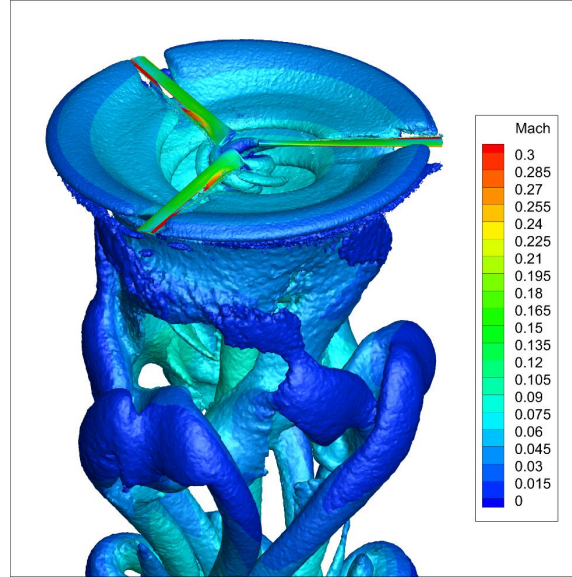
Isosurface of Q-criterion ($Q = 5e-8$) colored by Mach number.

Hover Mode, Low Pitch Angles

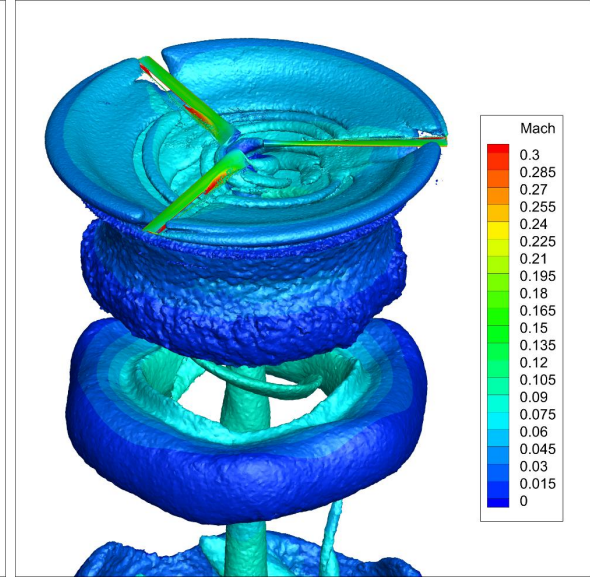
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Pitch angle = 0 deg



Pitch angle = 3 deg



Pitch angle = 5 deg

Downstream Wake

Axial

Circumferentially-average axial velocity is given by

$$\overline{v_a}(r) = \frac{1}{2\pi} \int_0^{2\pi} r v_a(r, \theta) d\theta$$

number of blades

Circumferential

Total non-dimensional circulation $B \cdot \Gamma(r)$ in Xrotor can be written as

$$B \cdot \Gamma(r) = 2\pi \frac{r}{R} \frac{\overline{v_t}(r)}{V_\infty}$$
$$\Rightarrow \overline{v_t}(r) = \frac{B \cdot \Gamma(r)}{2\pi r/R} V_\infty$$

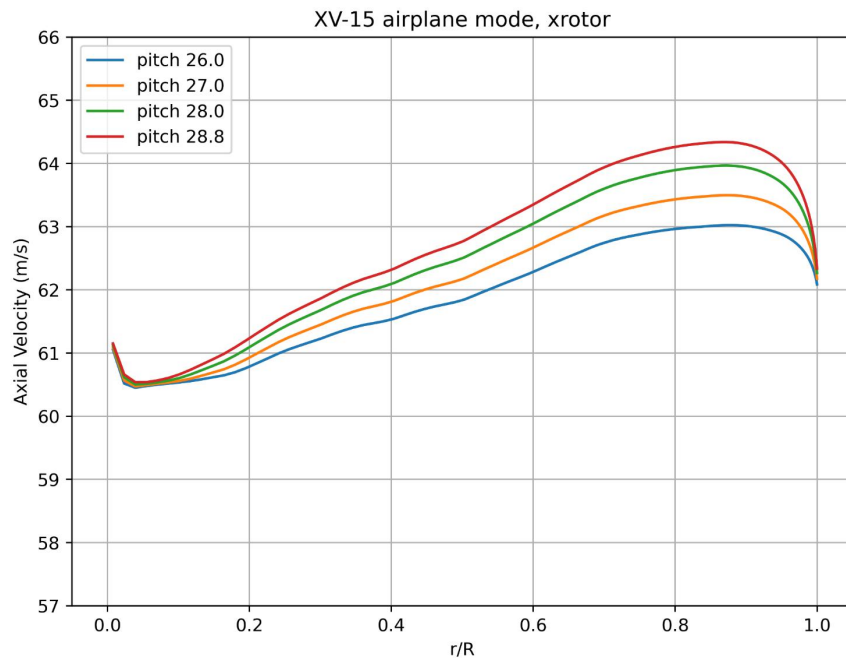
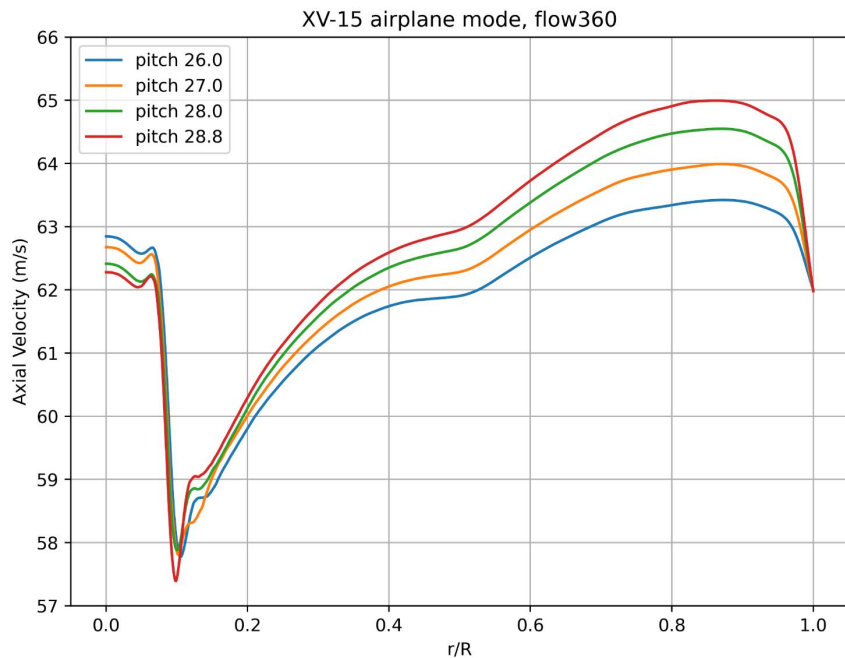
non-dimensional circulation on each blade
(denoted as GAM in Xrotor)

circumferentially-averaged
tangential velocity

Swirl can be written as

$$S(r) = \frac{1}{2\pi} \int_0^{2\pi} r v_t(r, \theta) d\theta = r \overline{v_t}(r)$$

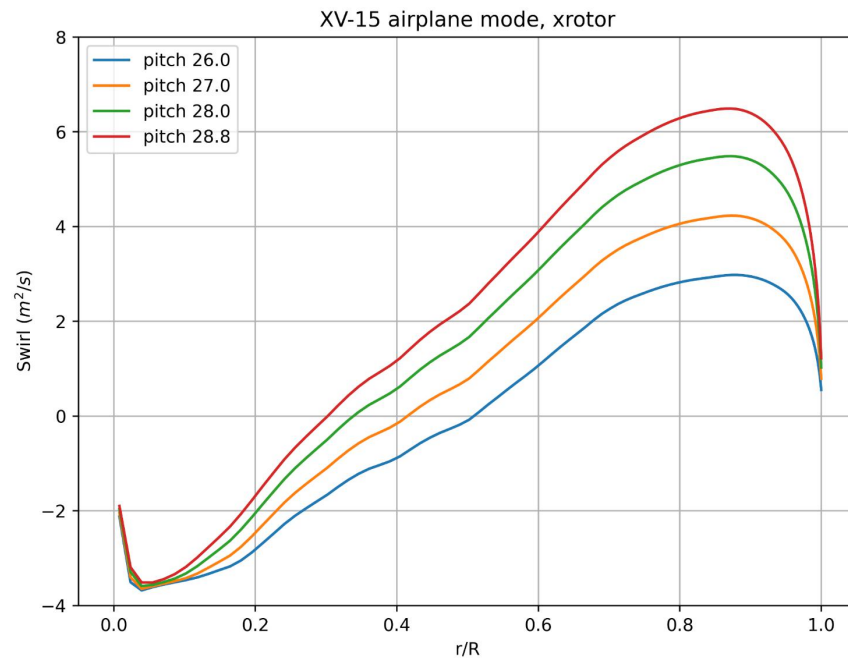
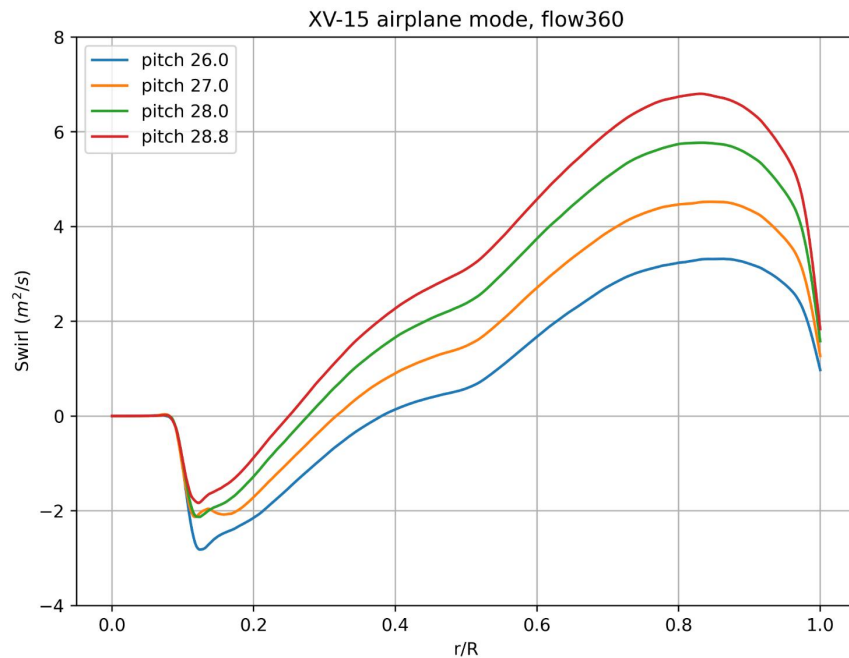
Airplane Mode, Axial Velocity





Airplane Mode, Swirl

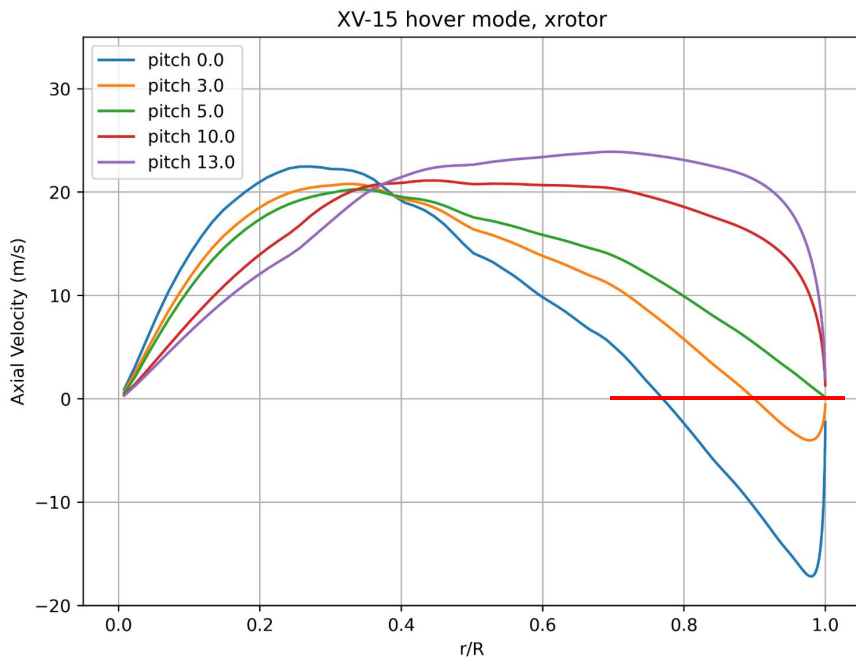
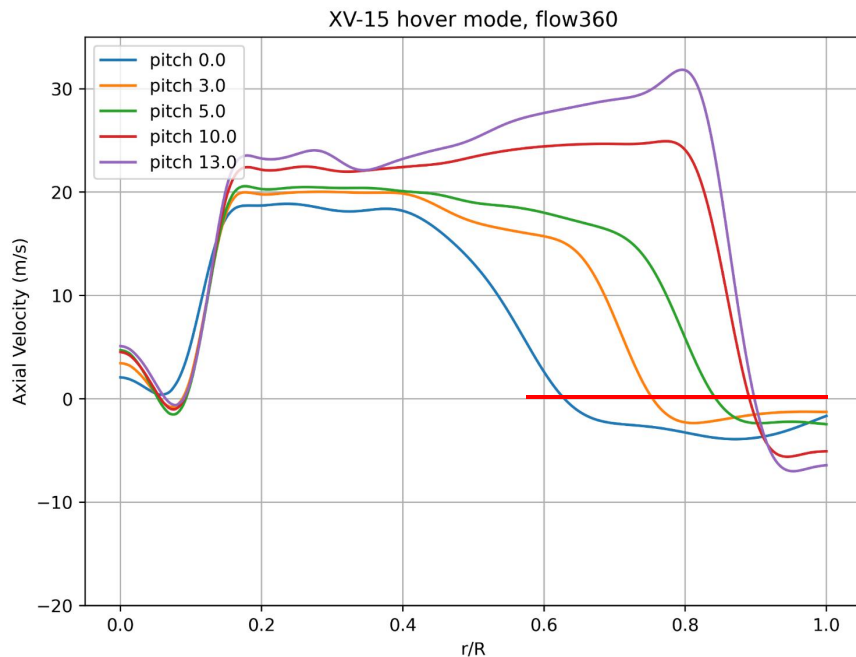
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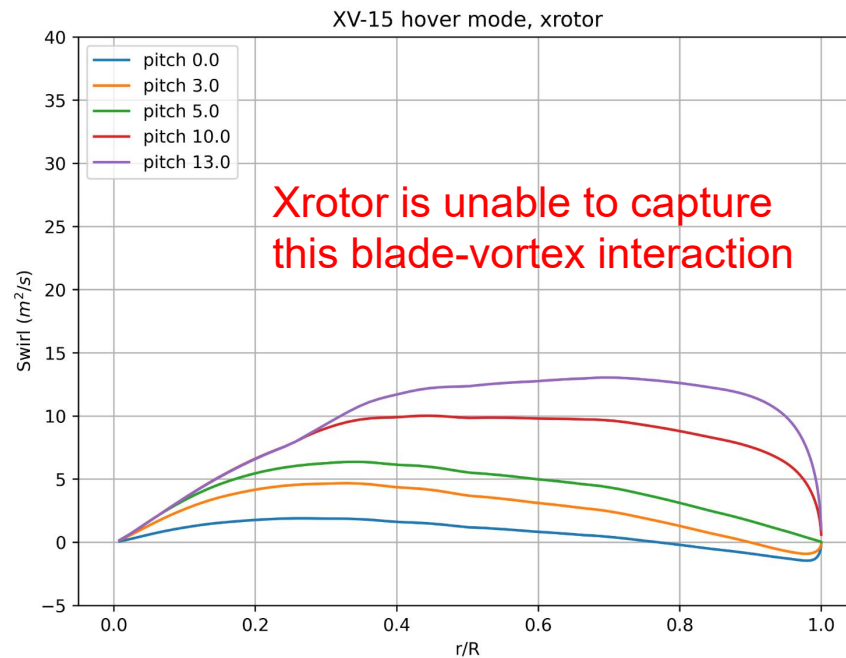
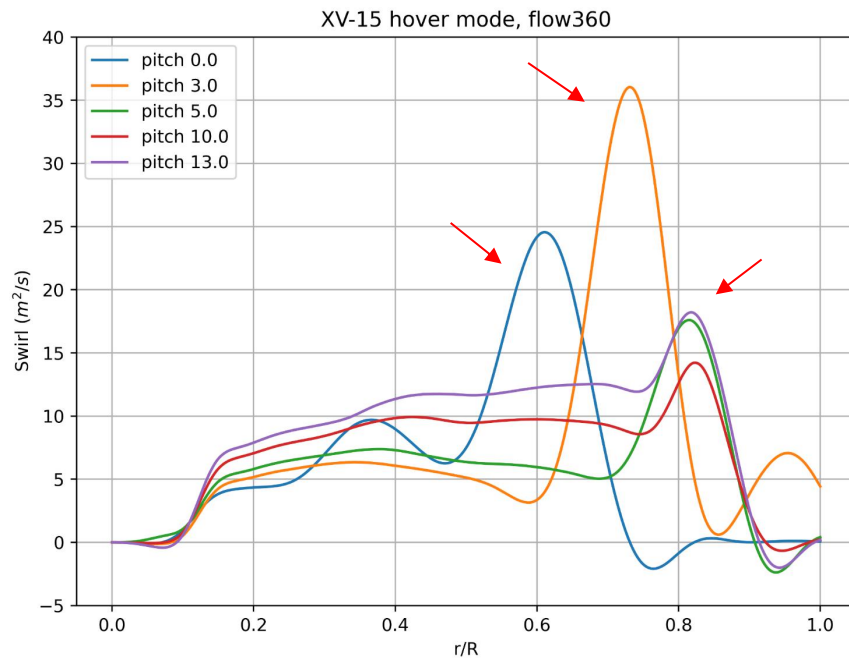
Hover Mode, Axial Velocity

$\overline{v_a}(r) < 0$ near the tip

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Hover Mode, Swirl

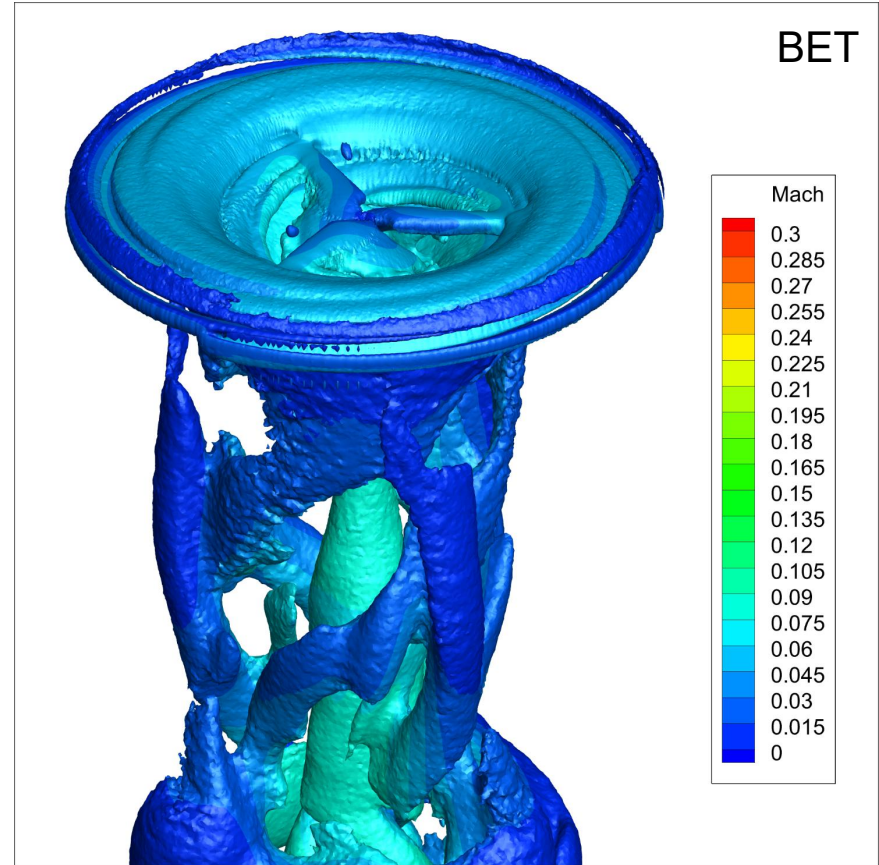
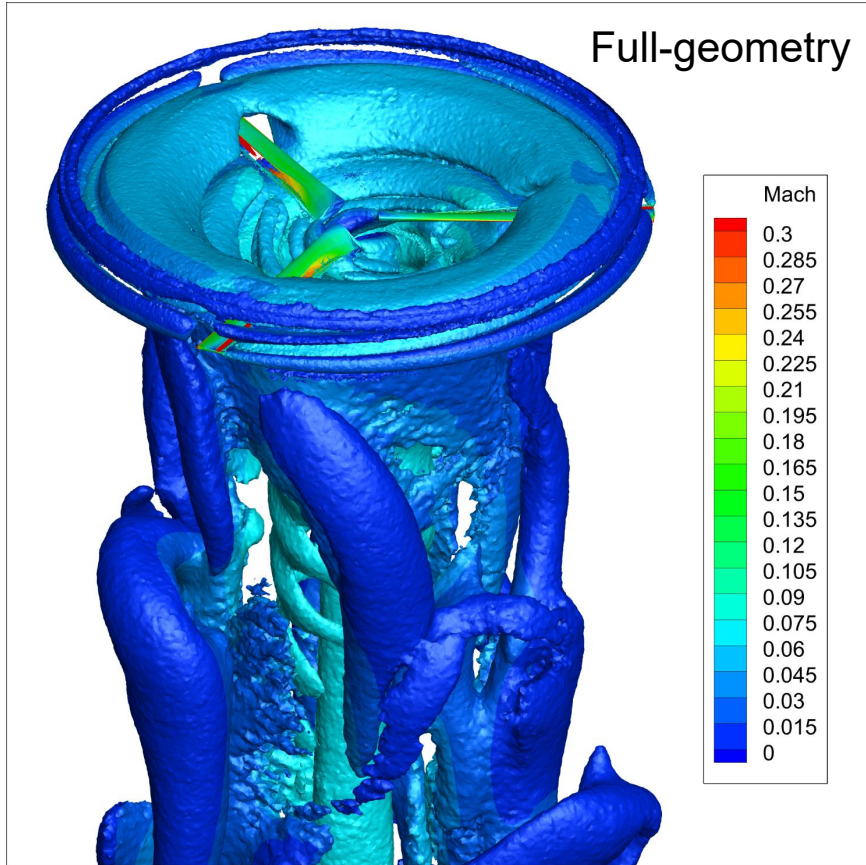


Blade Element Theory



Q-Criterion Isosurface

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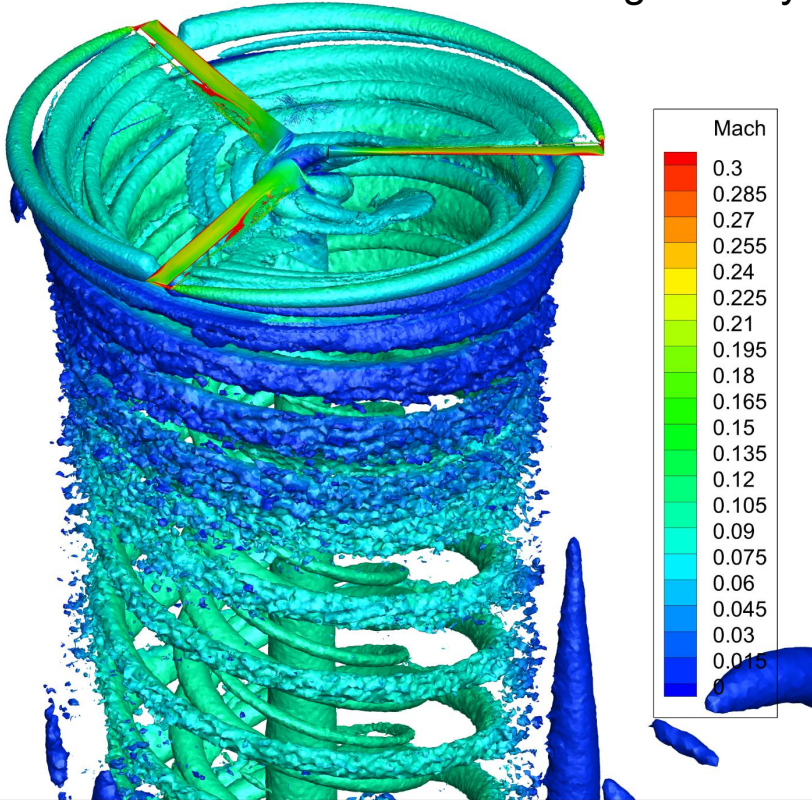
Hover mode, pitch angle = 0 deg ($Q = 5e-8$)



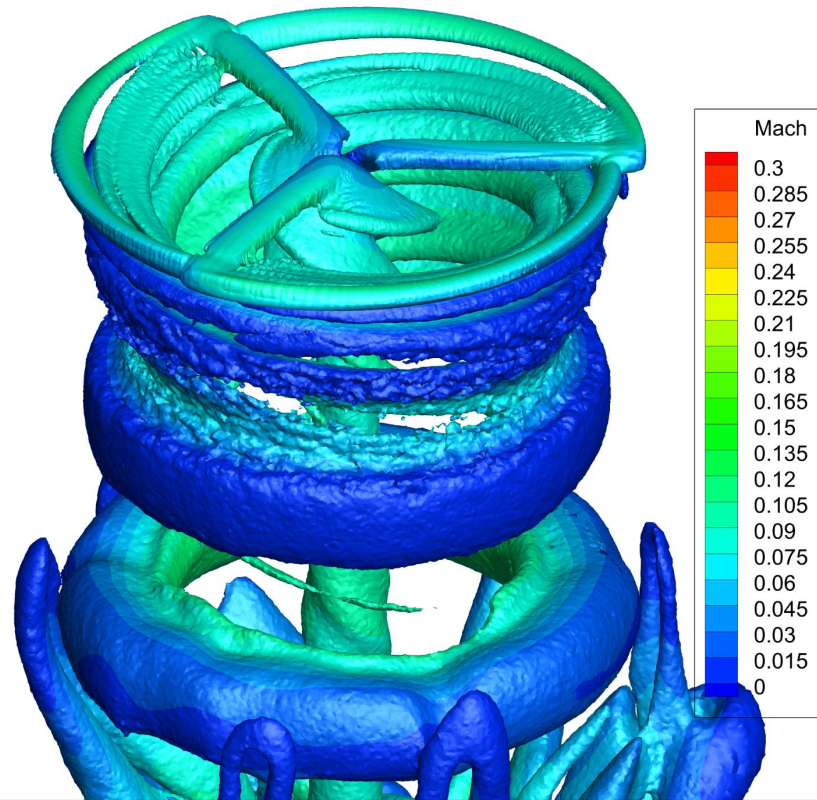
Q-Criterion Isosurface

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Full-geometry



BET



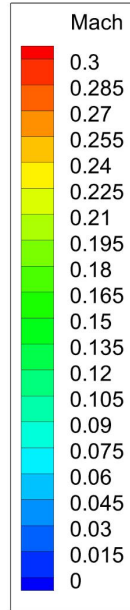
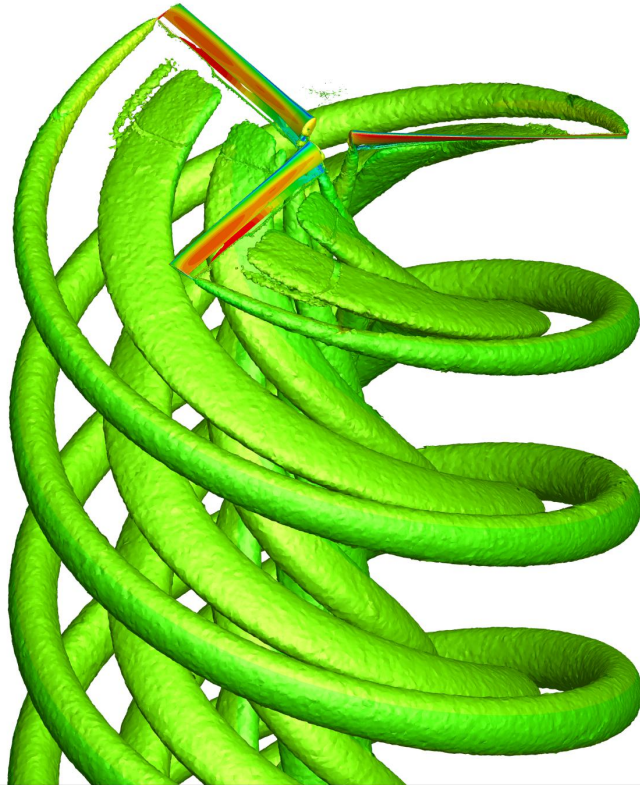
Hover mode, pitch angle = 10 deg ($Q = 5e-8$)



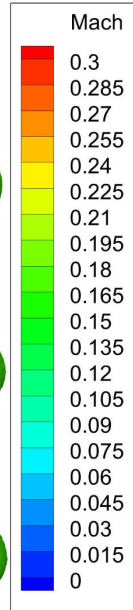
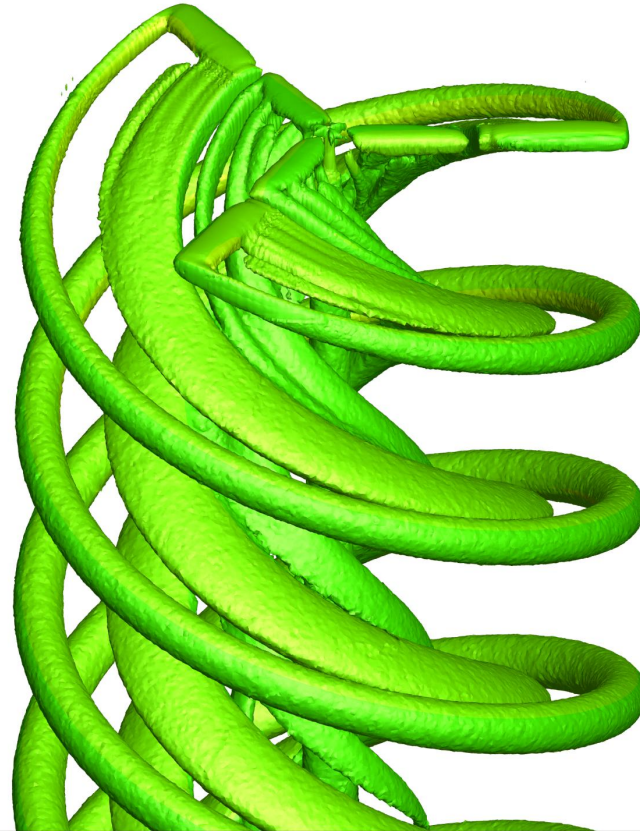
Q-Criterion Isosurface

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Full-geometry



BET

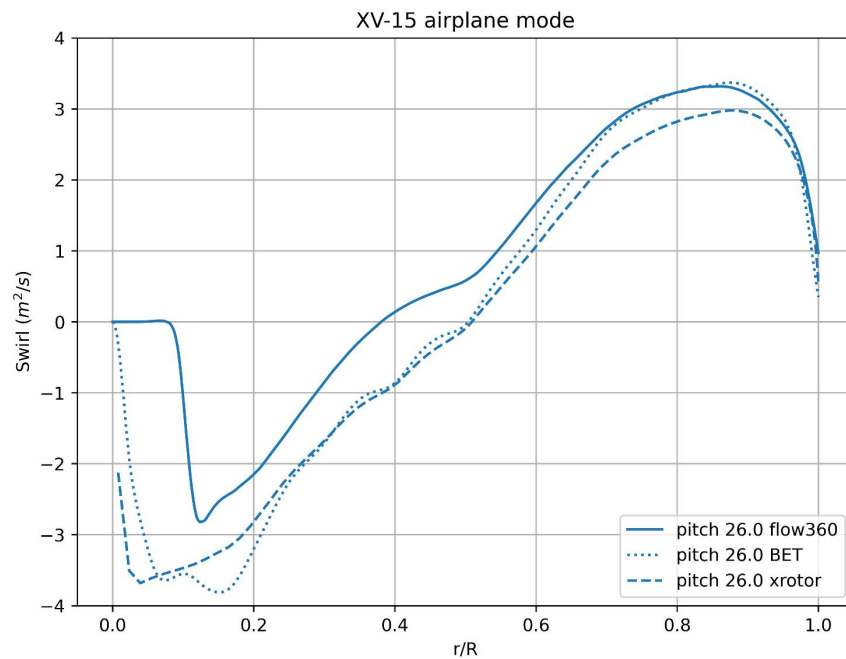
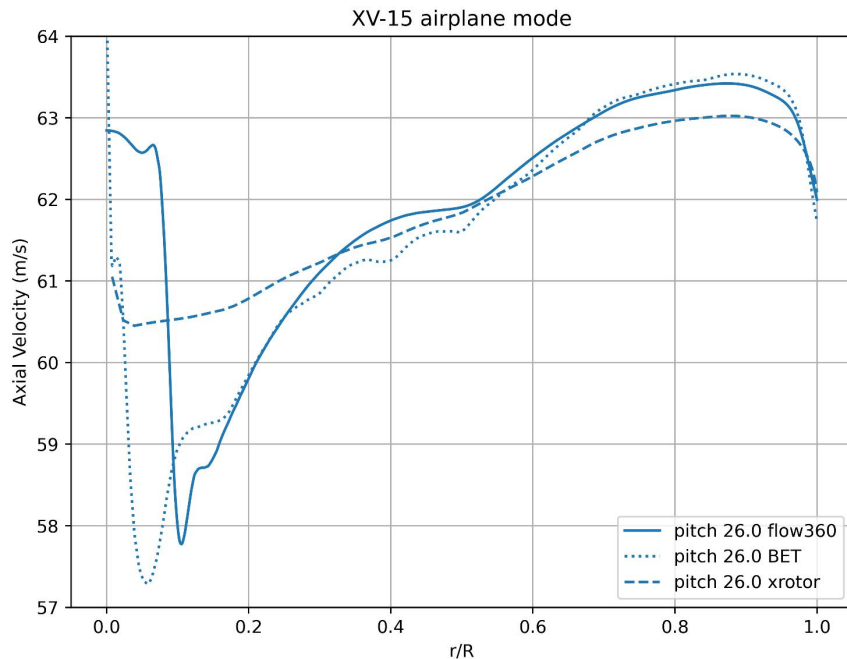


Airplane mode, pitch angle = 26 deg ($Q = 5e-8$)

Downstream Wake Comparison Flow360, BET and Xrotor

Airplane Mode

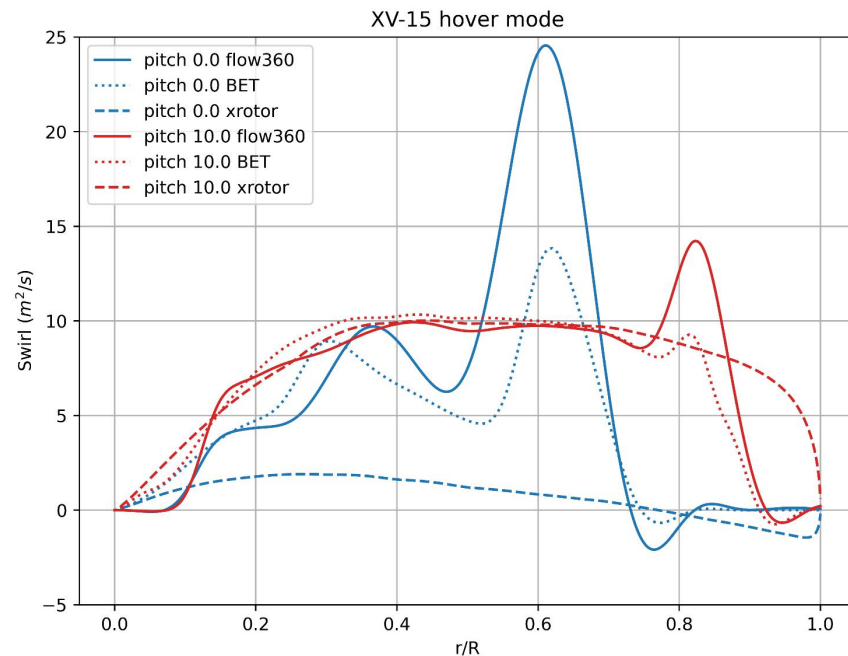
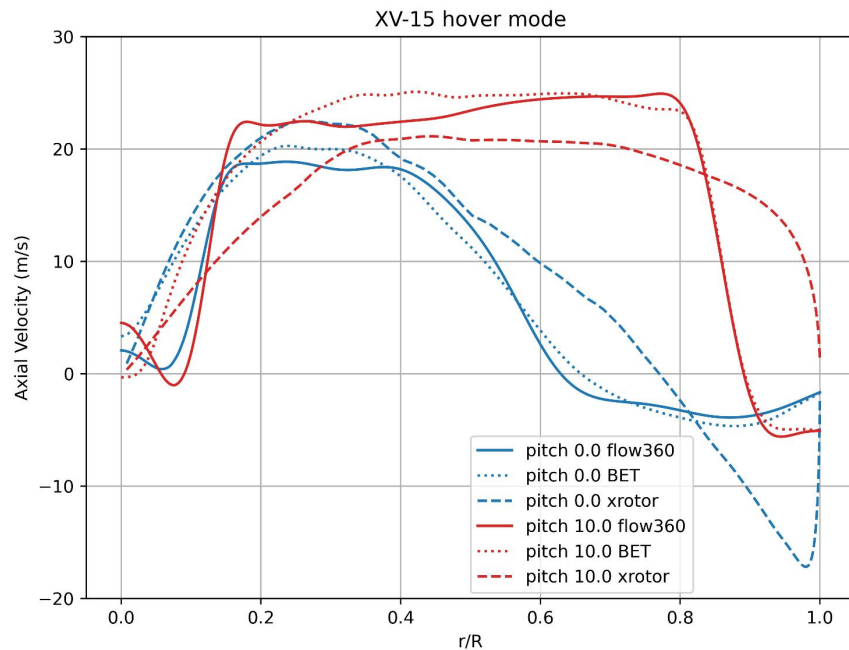
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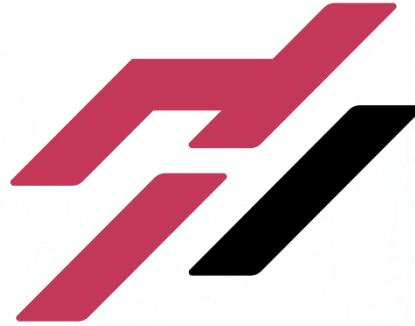
	Pitch	Flow360	BET	Xrotor
Thrust (N)	26.0 deg	3.96E+03	3.19E+03	3.06E+03
Torque (N·m)	26.0 deg	6.43E+03	5.30E+03	4.91E+03



Hover Mode



	Pitch	Flow360	BET	Xrotor
Thrust (N)	0.0 deg	4.44E+03	5.06E+03	1.06E+03
Torque (N·m)	0.0 deg	2.17E+03	1.87E+03	1.46E+03
Thrust (N)	10.0 deg	2.76E+04	2.87E+04	2.70E+04
Torque (N·m)	10.0 deg	9.17E+03	8.94E+03	8.29E+03

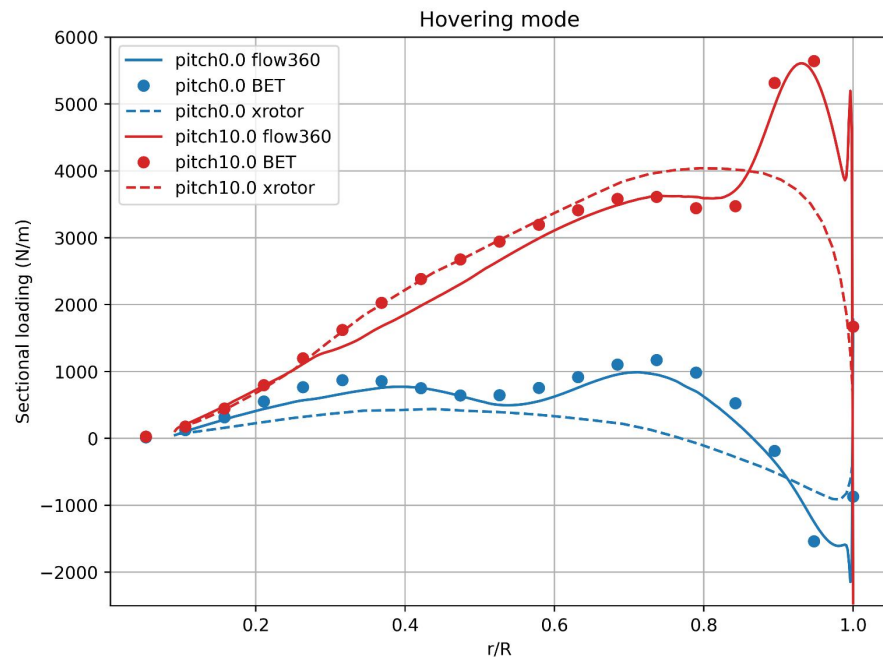
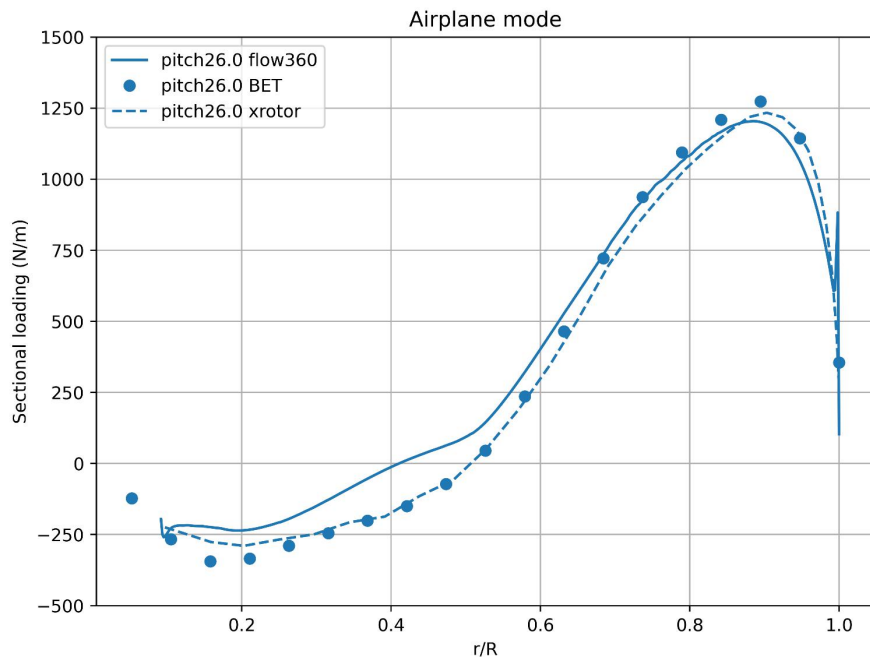


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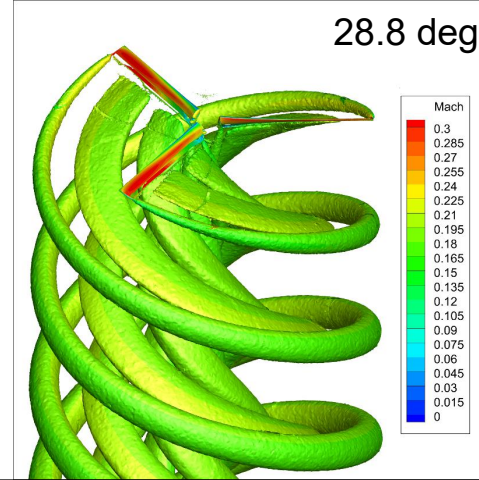
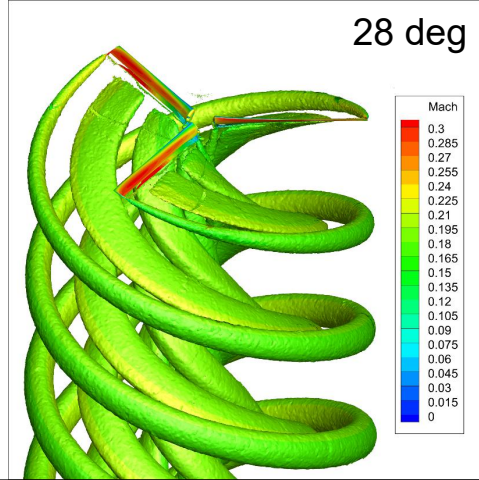
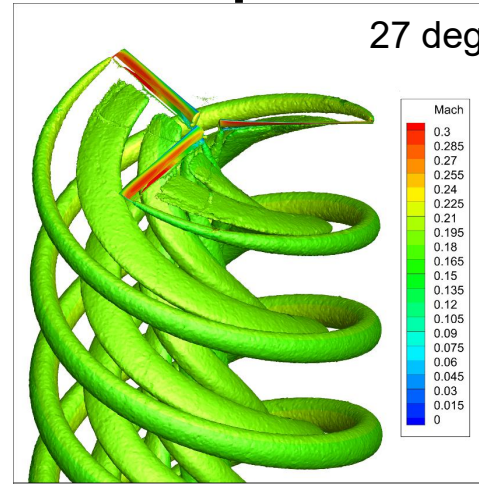
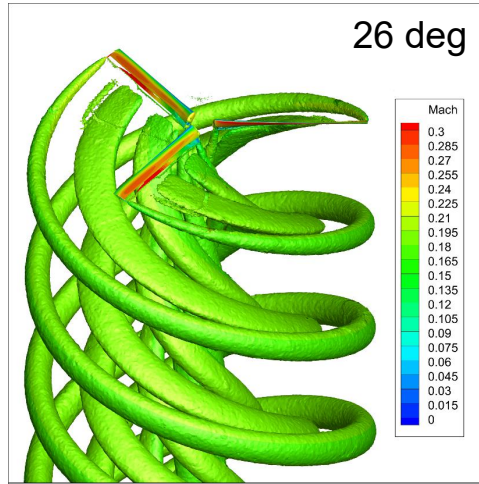
Sectional Loading BET

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Q-Criterion Isosurface, Airplane Mode





Q-Criterion Isosurface, Hover Mode

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