DECARBONIZATION OF MARINE TRANSPORTATION: A NECESSITY FOR GLOBAL ECONOMY AND OUR LIFE

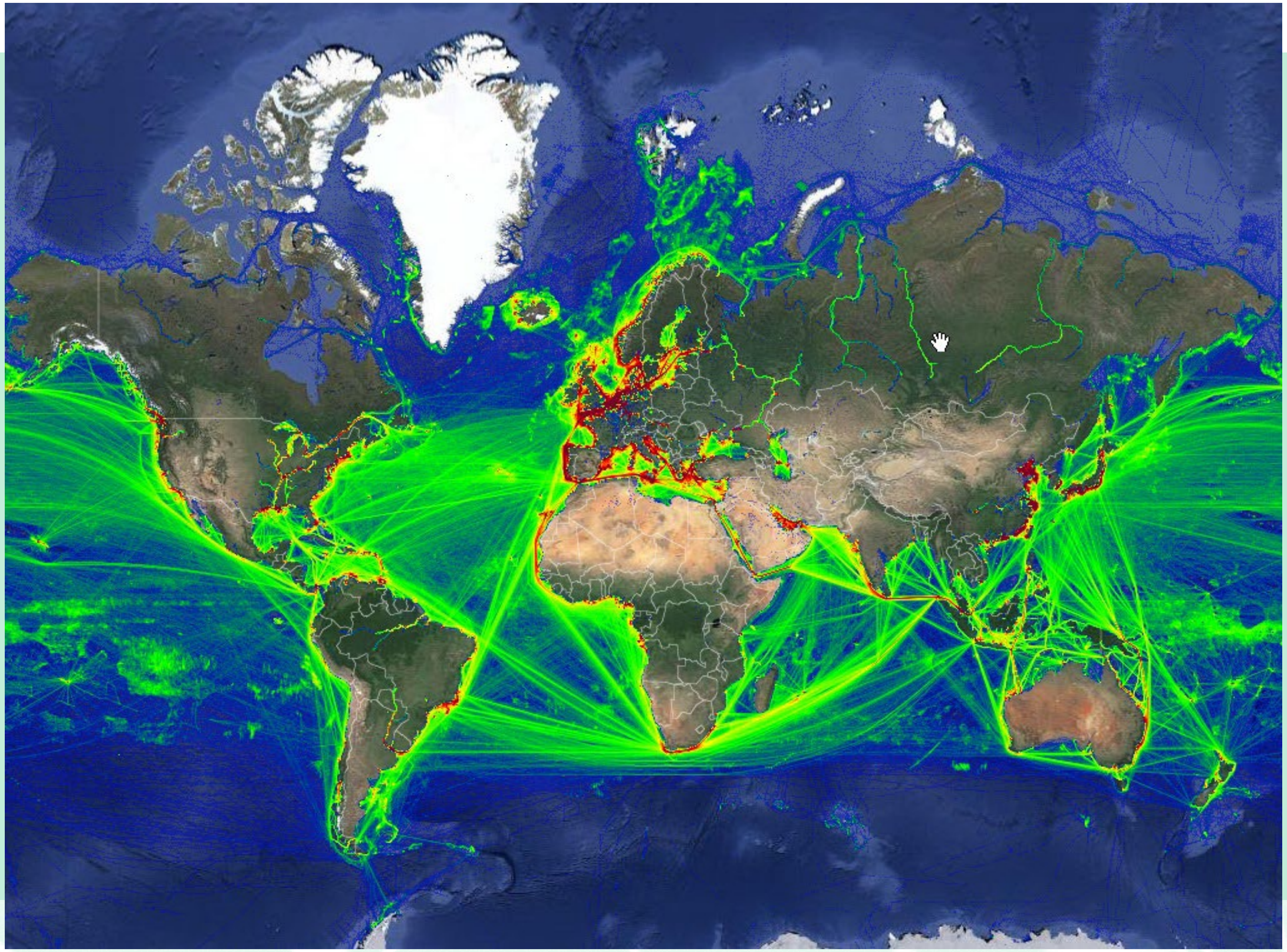
- 90% of global goods are transported by ships

- 2019*:
  - Cargo Ships: 100,000
  - Goods Shipped: 11 Billion Tons
  - CO_2 Emission: 1.076 Billion Tons
  - Fuel Burned: 230 Million Tons
  - Fuel Cost: $165 Bn ($700/ton)

- EMISSION
  - 1 of the largest ships:

= 50 million cars#

Marine Ship Traffic | Tracked by Google Maps



* White paper: Wind Propulsion for Ships, Wind Ship Association, France, Sept. 2022

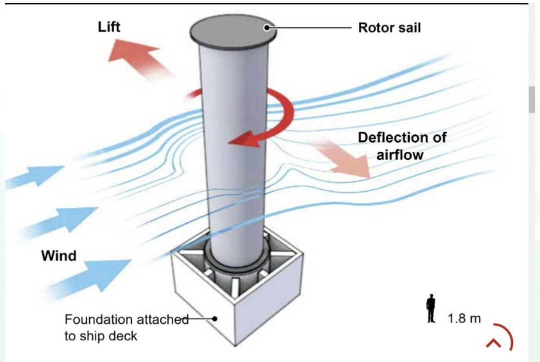
E. Stratiotis, "Fuel Cost in Ocean Shipping", 1/22/2018

THE OCEAN IS RICH IN WIND POWER: CLEAN, SUSTAINABLE, AND PREDICTABLE

- Conventional flexible wind sails: large, ineffective, inefficient, difficult to control.
- Too weak to power modern cargo ships.

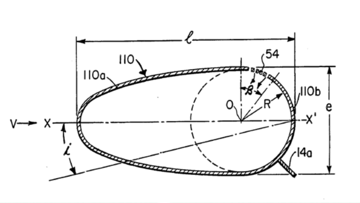
PROBLEMS OF CURRENT RIGID WIND SAILS: LOW THRUST, COMPLEX, HIGH COST, LONG ROI

FLETTNER ROTORS: Spinning Cylinders



Credit: Katherine Kornei, 2017

TURBOSAILS



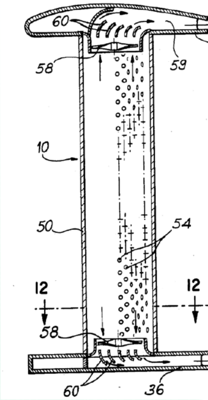
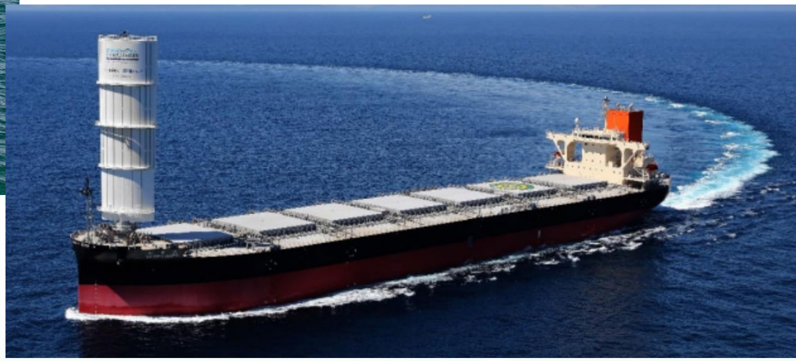
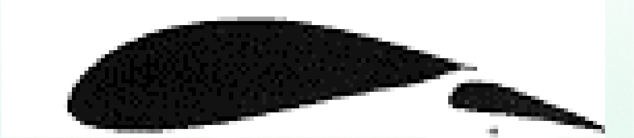


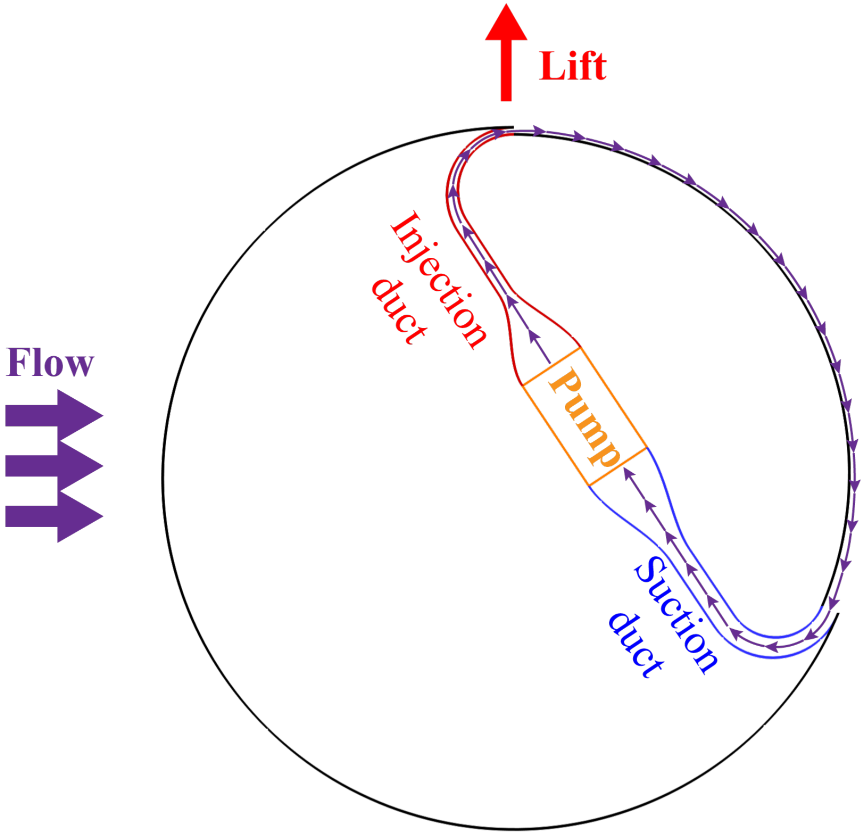
FIG.

RIGID, THICK WINGS:





OUR SOLUTION – COFLOW JET (CFJ) STATIONARY CYLINDER: ULTRA-HIGH NET LIFT AND POWER



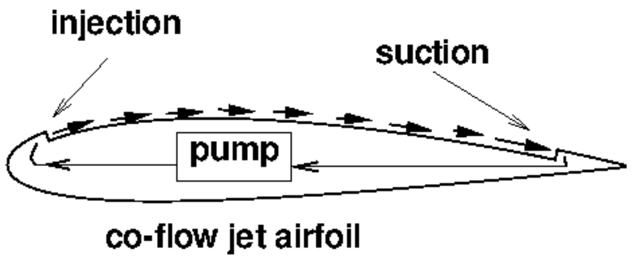
COFLOW JET STATIONARY CYLINDER WIND SAILS:

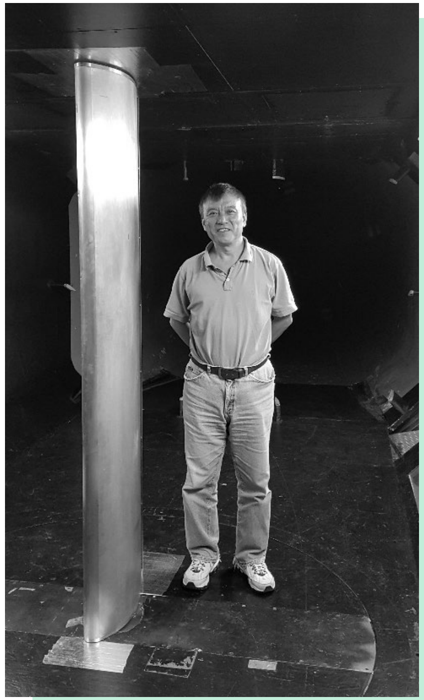
- No rotation, simple system
- Low pressure fans embedded inside the cylinder
- Sucks a small amount of air flow at the 4 o'clock position, pressurized by the fans, and ejects the air mass tangent to the surface at the 12 o'clock position
- Ultra-high lift coefficient (CL>20) from wind
- Very low power required
- Ultra-high net propulsive power from wind
- Originated from Aeronautics Research
- Verified numerically and experimentally in U.S. National Laboratories

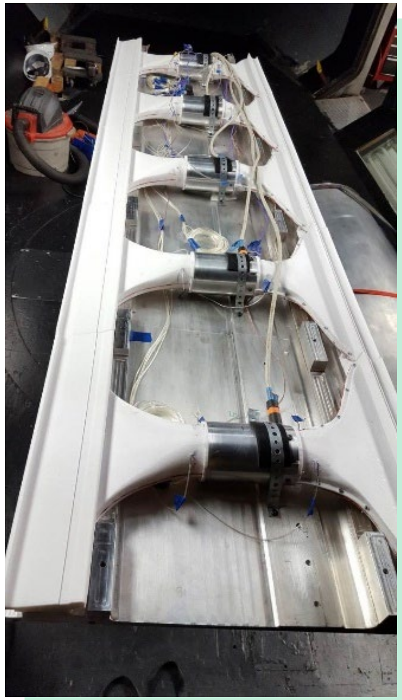
OUR SOLUTION – COFLOW JET (CFJ) STATIONARY CYLINDER: UNIQUE AND SUPERIOR

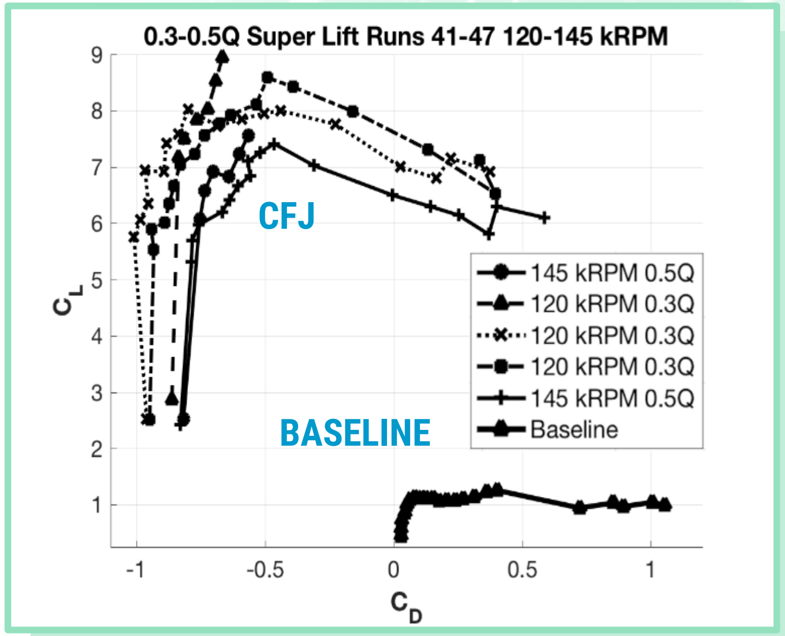
WIND TUNNEL TESTING UNDER DARPA FUNDING

- 18 Patents issued
- 20 Years research
- Grants received: $2.5 Mn (DARPA, NASA, NSF, AFRL, ARO, CIRA, EBPT, …)





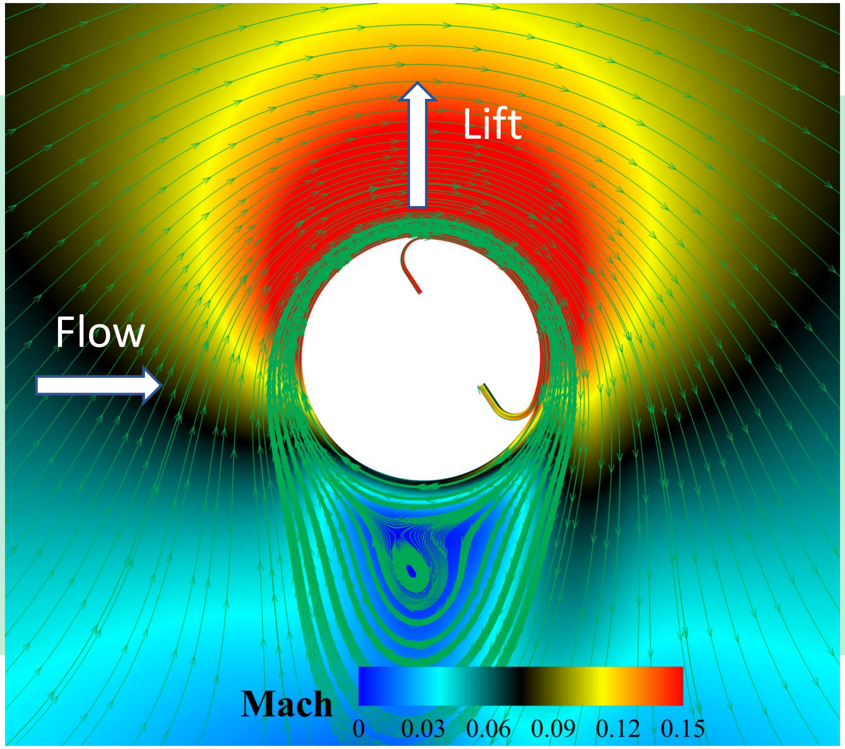




COFLOW JET CONCEPT EXPERIMENT ANIMATION

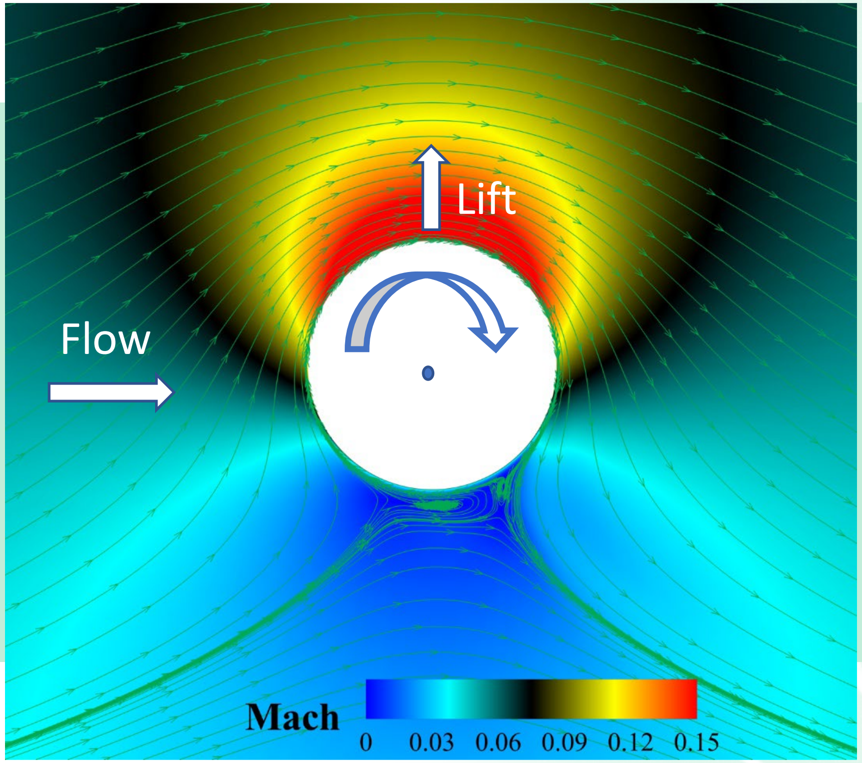
COMPARISON OF COFLOW JET CYLINDER WITH FLETTNER ROTOR BY CFD

CoFlow Jet Cylinder



CL=15, Pc=3.3
High Lift

Flettner Rotor



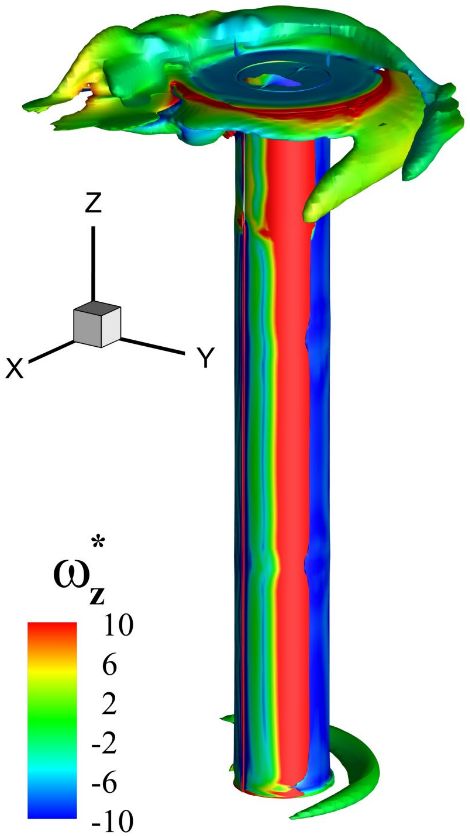
CL=5, Pc=0.7
(weight=0, V_{rotate}/V_{∞} =3)

Summary: Reducing CL decreases CFJ power exponentially; Two cases studied: CL=15.3, CL=7.6

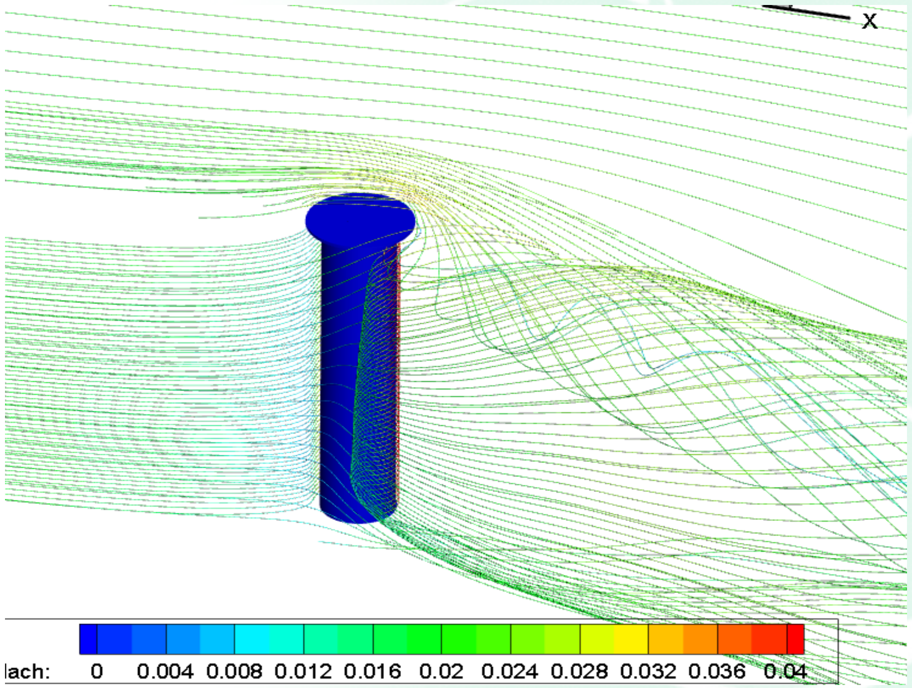
Table 1 CFJ sail compared with a Fletter rotor

Cases	CL	CD	PC	CL/CD	CL/PC	AR	Cmu
Flettner rotor (FR)	5.000	1.90	0.70	2.632	7.143	2D test	Vrot/ V_∞ =3
CFJP	15.30	4.20	3.30	3.643	4.636	8	1.0
CFJE	9.930	3.37	0.77	2.947	12.90	5	0.5
CFJE2	7.6	2.15	0.35	3.53	21.71	5	0.3

Case 1: CFJ Performance (CFJP): CL=15.3, Pc=3.3, AR=8

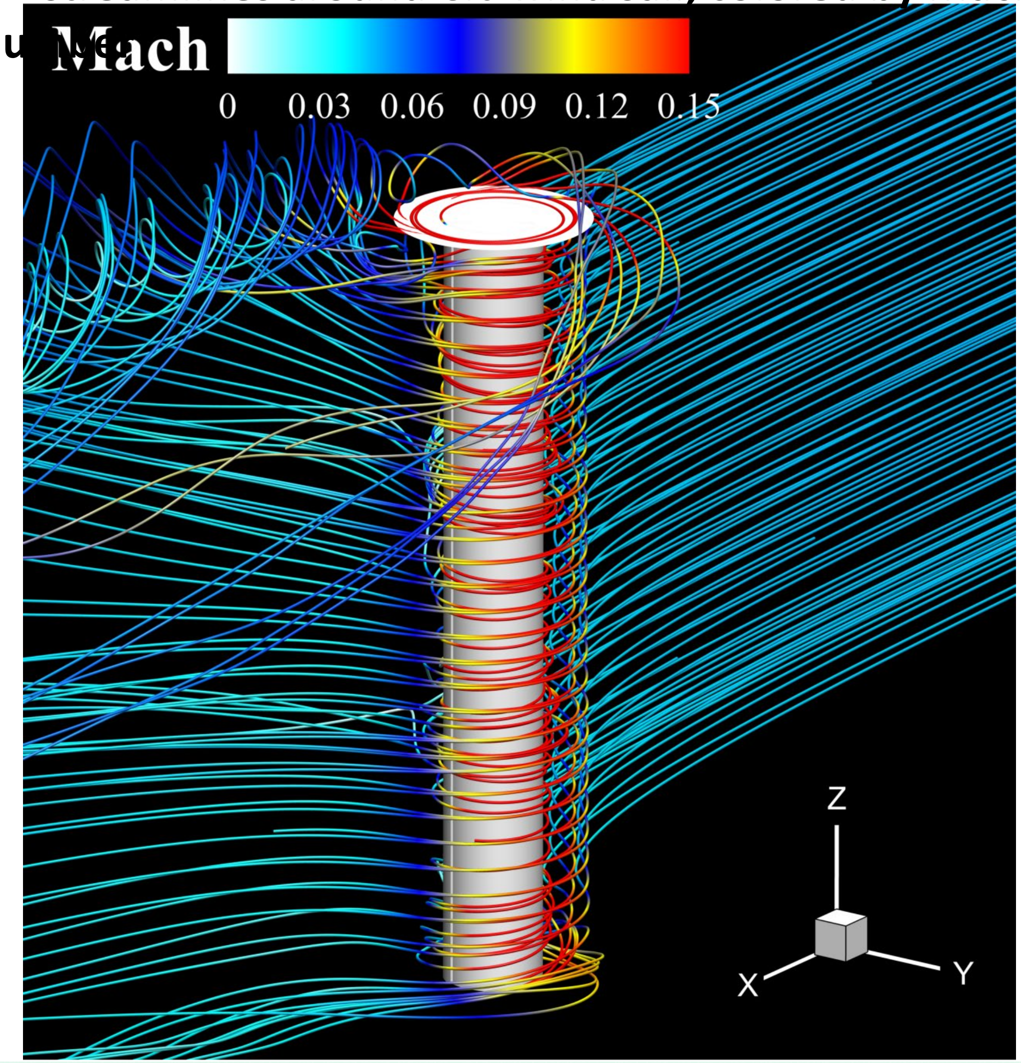


Case 2: CFJ Efficiency (CFJE): CL=9.93, Pc=0.77, AR=5

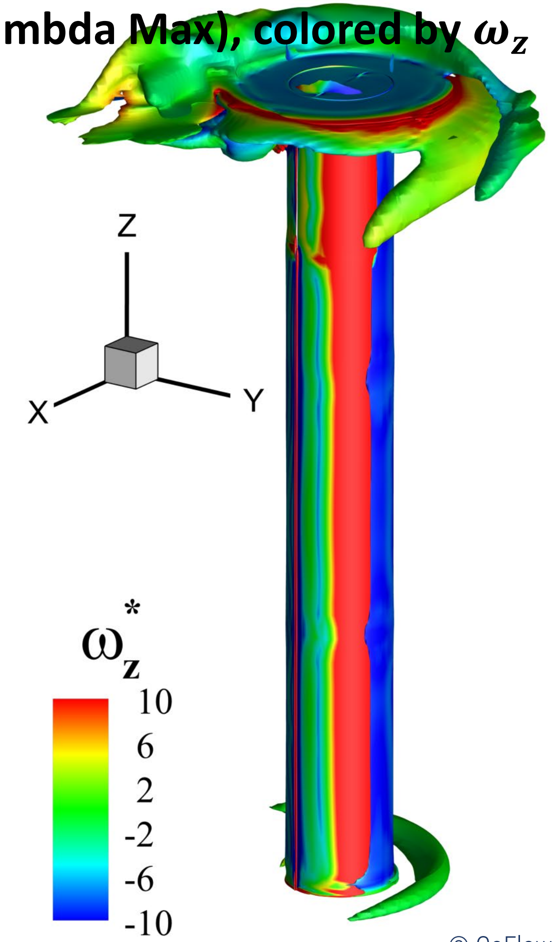


3D flow structures for CFJP

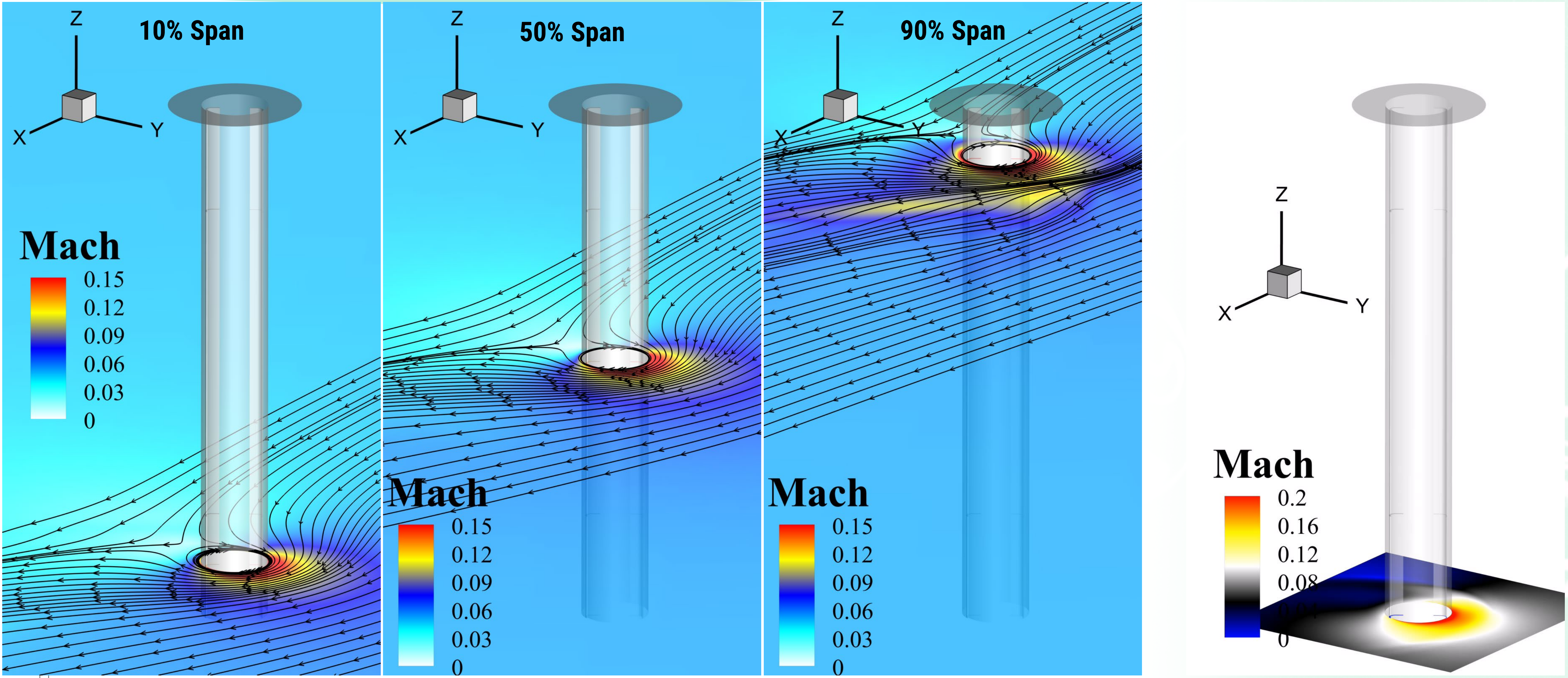
- 3D streamlines around CFJ wind sail, colored by Mach number



- Vorticity structures (iso-surface of Lambda Max), colored by ω_z



3D flow structures for CFJP



CFJ sail net power across the full AWA range

$$P_{net} = 0.5\rho V^3_{AWS}\, S[V_{ratio}*(CL*\sin(AWA)-CD*\cos(AWA)) - Pc]$$

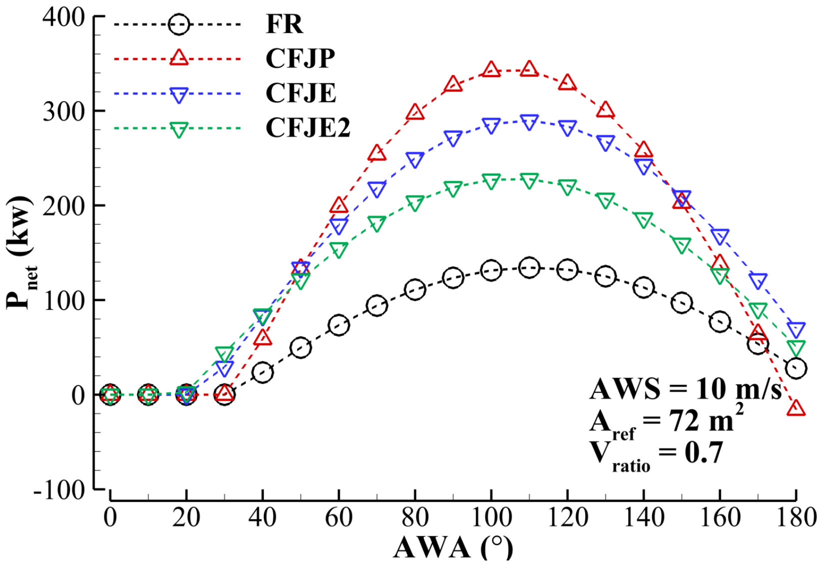
Example Sail:

- Diameter: 3m
- Height: 24m
- AWS(apparent wind speed): 10m/s
- AWA: apparent wind angle
- $V_{ratio} = V_{ship}/V_{AWS}$
- $P_{net} = P_{tot} - P_{FR/CFJ}$

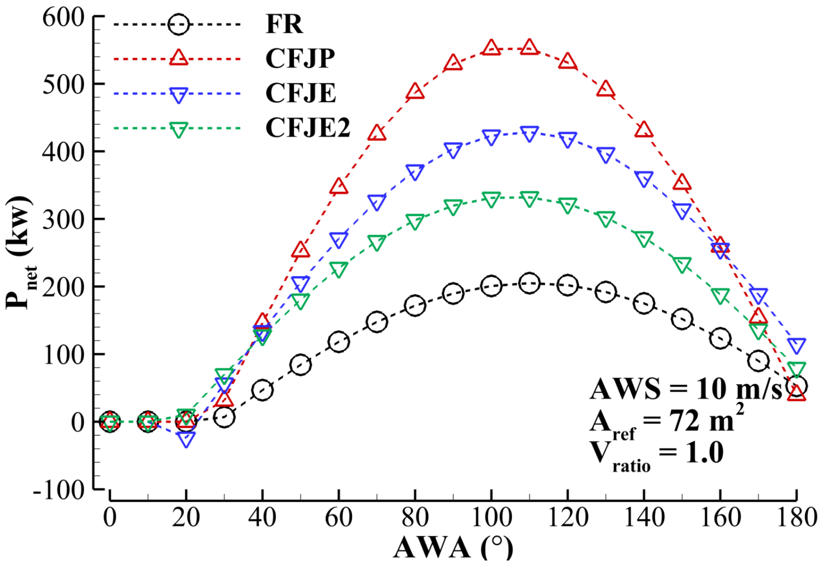
An efficient strategy is to use CFJE and CFJP mode at different AWA:

1) CFJE for headwind or tailwind with AWA <40-60deg, AWA>140deg
2) CFJP mode between 40deg and 140deg.

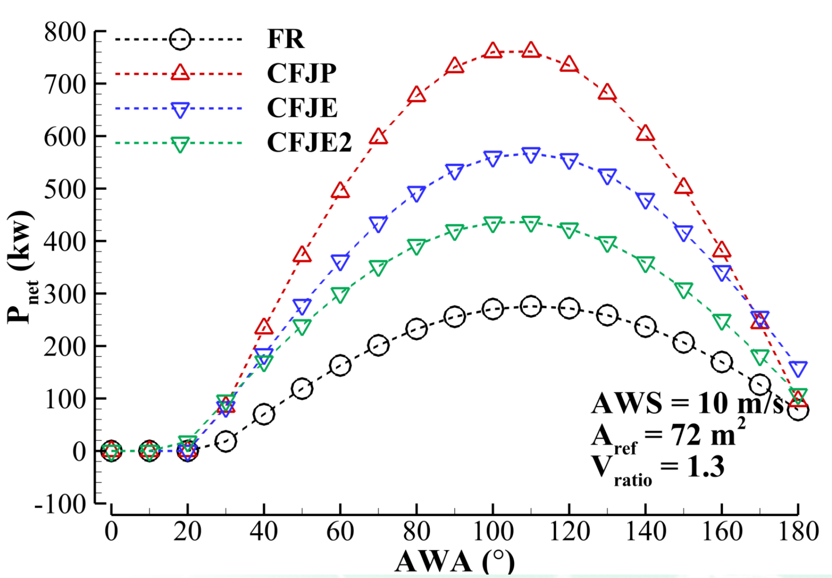
Net Power Production Comparison at Different Velocity Ratios



$V_{ratio} = 0.7$



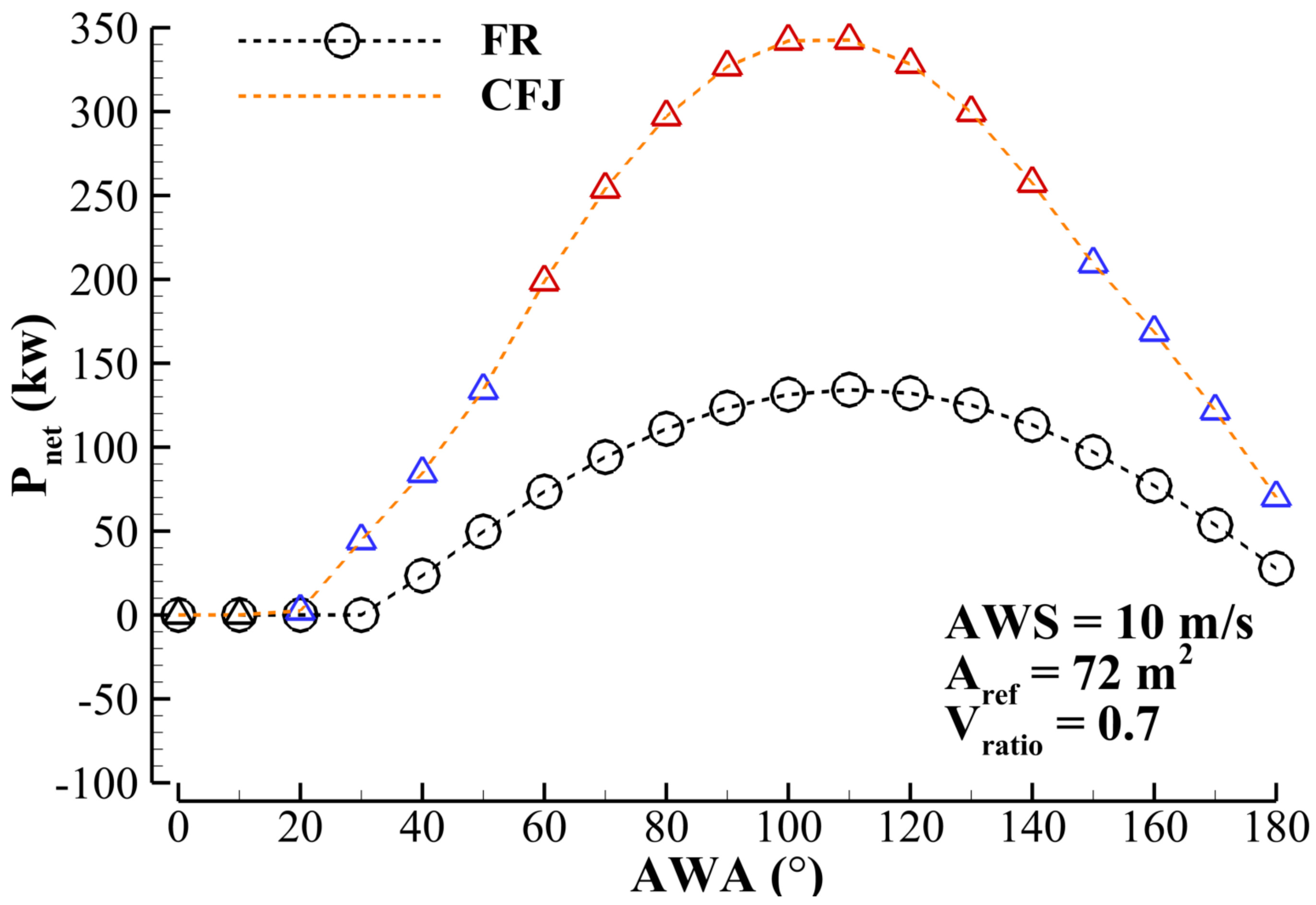
$V_{ratio} = 1.0$



$V_{ratio} = 1.3$

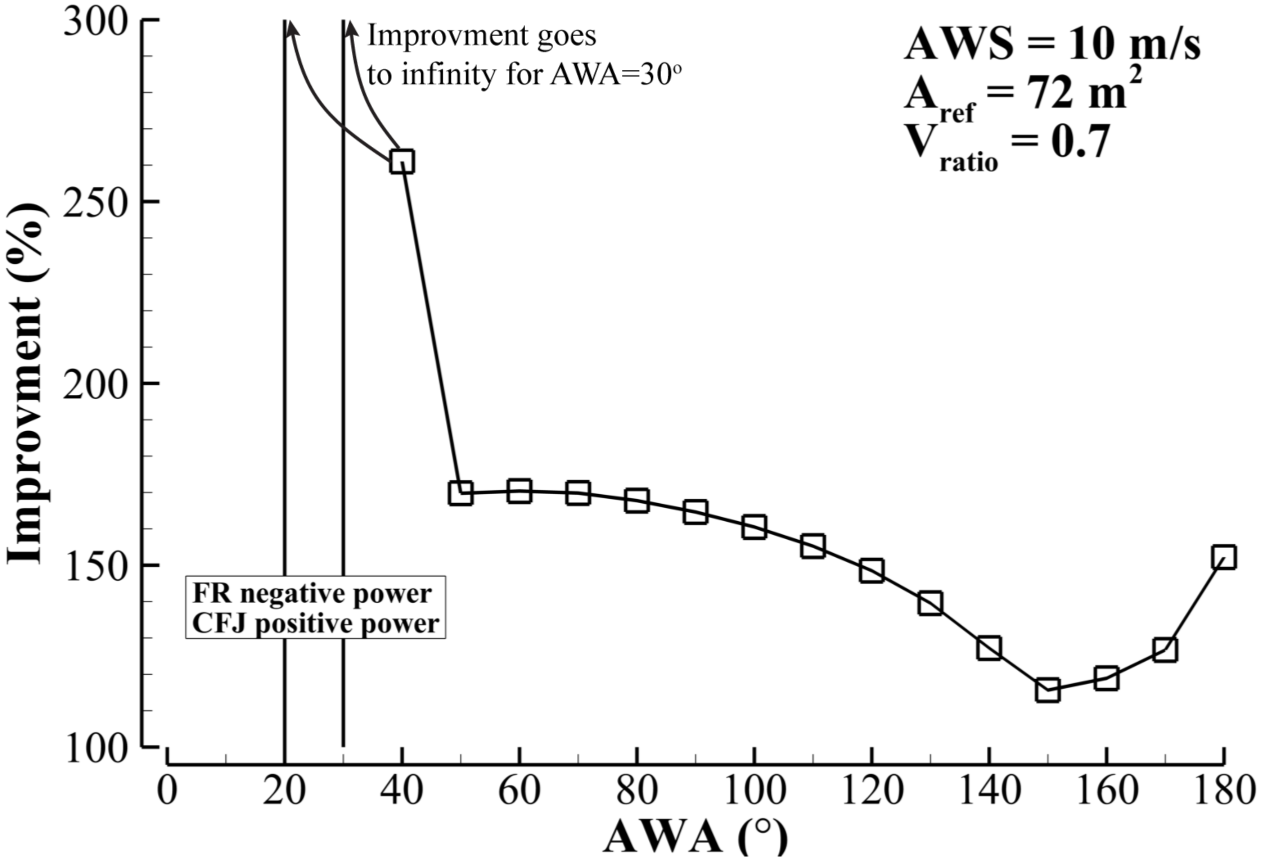
- At low ship speed Vratio ≤1, CFJE and CFJE2 are more efficient at near headwind and tailwind conditions.
- At high ship Vratio >1, CFJP could be efficient for the whole AWA range.
- CFJ wind sails generate significantly more net power than Flettner Rotor across the whole range of AWA.

Net Power Comparison with Combined CFJ Modes: Velocity Ratio = 0.7



- Blue symbol indicates CFJE or CFJE2 and red symbol indicates CFJP
- CFJE modes to be used near head wind or tail wind conditions.
- CFJP mode to be used in side wind conditions.
- CFJ wind sails generate significantly more net power than Flettner Rotor across the whole range of AWA.

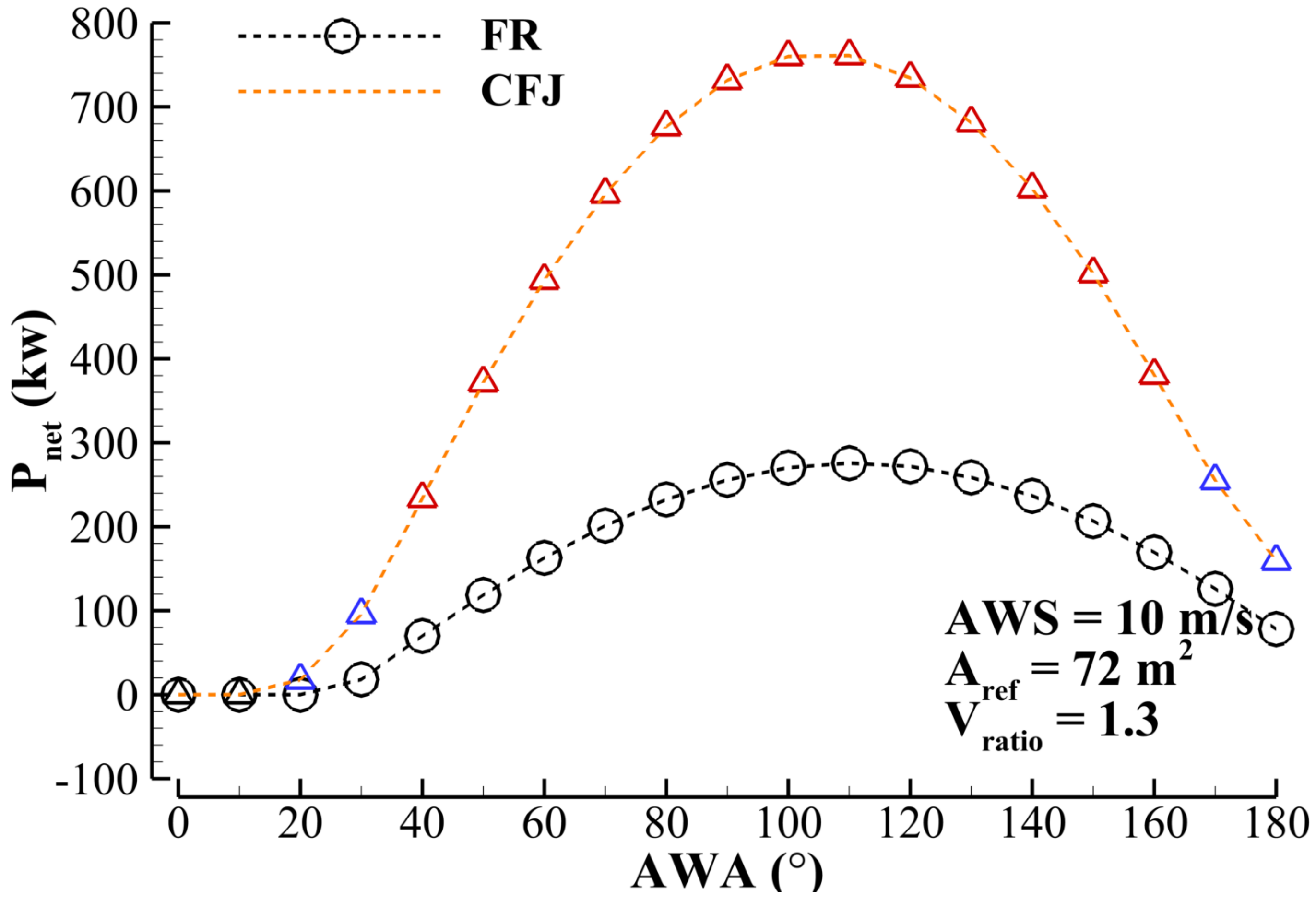
CFJ Wind Sail Net Power Improvement over Flettner Rotor: Velocity Ratio = 0.7



AWA (deg.)	FR net power (kw)	CFJ WS net power (kw)	Improve (%)
0.000	-89.523	-81.806	0.000
10.000	-61.829	-18.822	0.000
20.000	-33.195	2.439	∞
30.000	-4.490	44.392	∞
40.000	23.413	84.528	261.023
50.000	49.668	133.995	169.784
60.000	73.475	198.676	170.402
70.000	94.111	253.953	169.844
80.000	110.950	297.091	167.770
90.000	123.480	326.781	164.643
100.000	131.320	342.120	160.524
110.000	134.232	342.641	155.261
120.000	132.128	328.330	148.495
130.000	125.070	299.621	139.562
140.000	113.275	257.386	127.222
150.000	97.100	209.407	115.661
160.000	77.037	168.644	118.914
170.000	53.695	121.724	126.698
180.000	27.783	70.075	152.222

- CFJ wind sails have wider AWA range and generate significantly more net power than Flettner Rotor, > 115% across the full AWA range.

Net Power Comparison with Combined CFJ Modes: Velocity Ratio = 1.3



- Blue symbol indicates CFJE or CFJE2 and red symbol indicates CFJP
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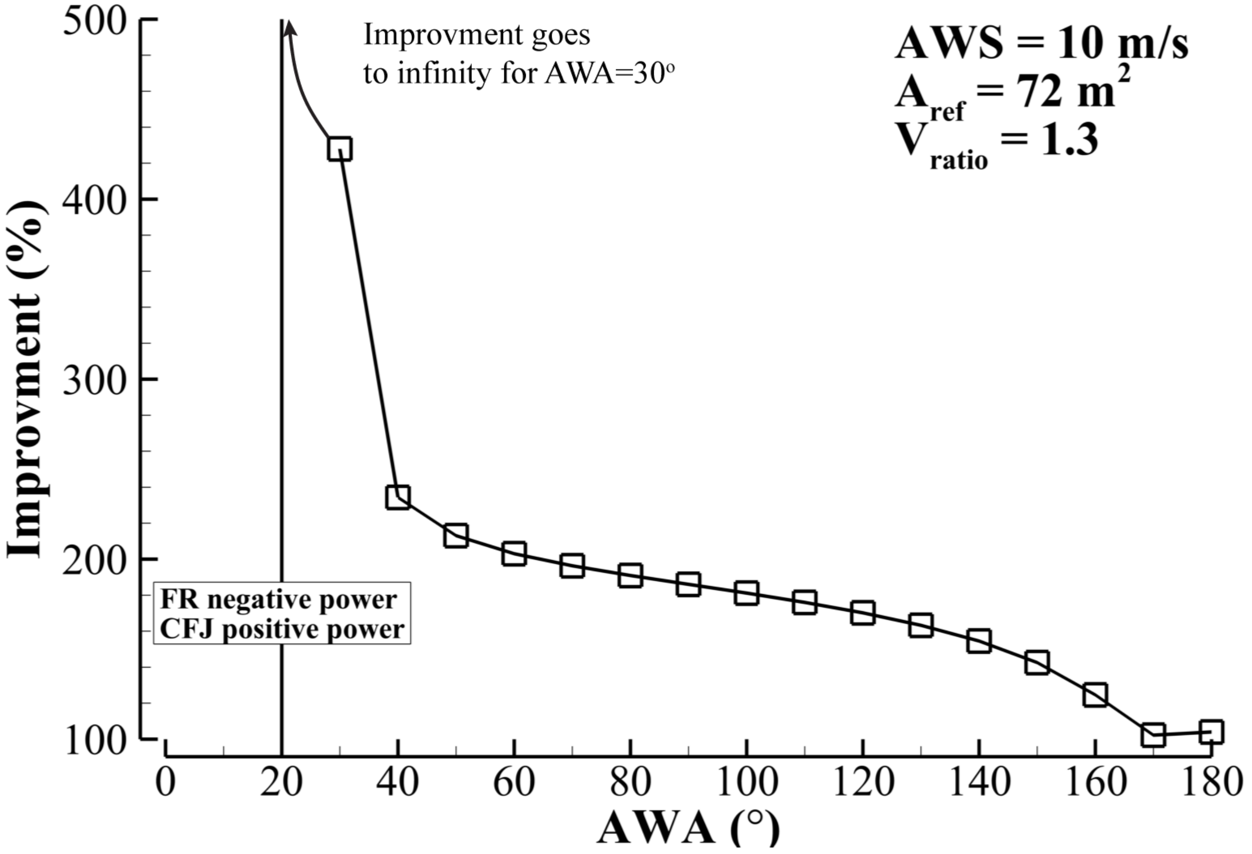
CFJ Wind Sail Net Power Improvement over Flettner Rotor: Velocity Ratio = 1.3

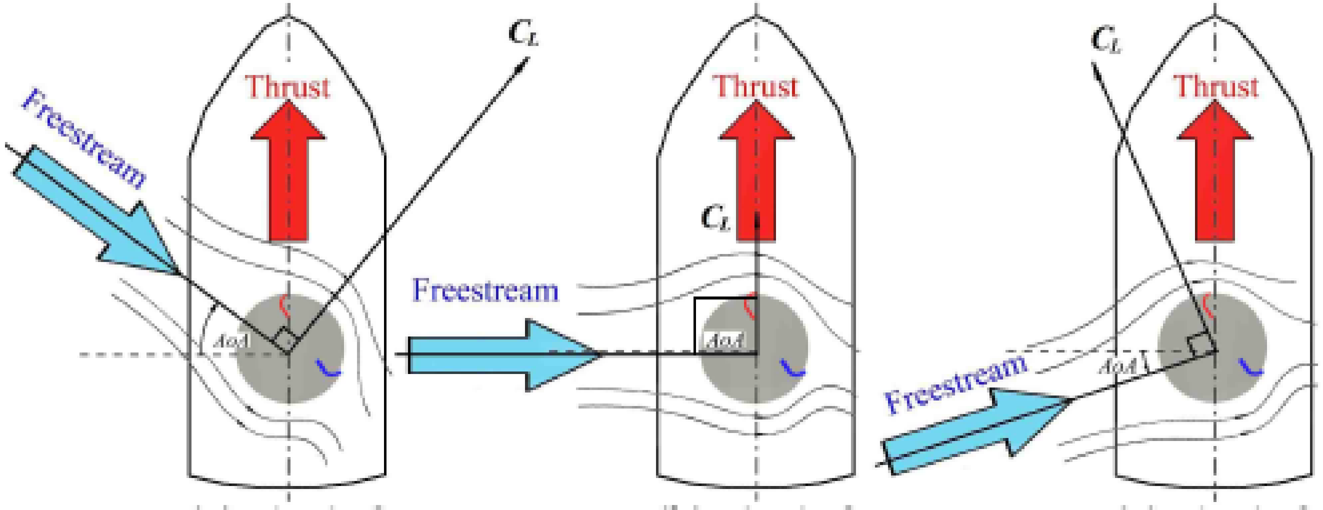


AWA (deg.)	FR net power (kw)	CFJ WS net power (kw)	Improve (%)
0.000	-139.797	-138.695	0.000
10.000	-88.366	-21.725	0.000
20.000	-35.188	17.760	∞
30.000	18.121	95.673	427.955
40.000	69.942	233.838	234.330
50.000	118.700	371.631	213.085
60.000	162.913	493.710	203.052
70.000	201.238	596.367	196.349
80.000	232.510	676.481	190.947
90.000	255.780	731.619	186.034
100.000	270.340	760.105	181.166
110.000	275.748	761.074	176.003
120.000	271.840	734.496	170.195
130.000	258.734	681.179	163.274
140.000	236.828	602.743	154.507
150.000	206.789	501.571	142.553
160.000	169.528	380.737	124.587
170.000	126.178	255.166	102.226
180.000	78.057	159.245	104.011

- CFJ wind sails generate significantly more net power than Flettner Rotor, > 100% across the full AWA range, much more at low AWA.

Angle of Attack Variation Tolerance (2D)

➤ Definition of Thrust Coefficient:

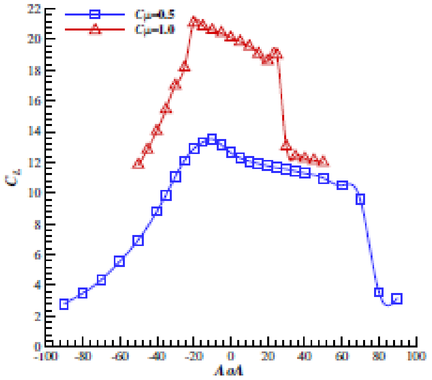


(a) $AoA<0$ (b) $AoA=0$ (c) $AoA>0$

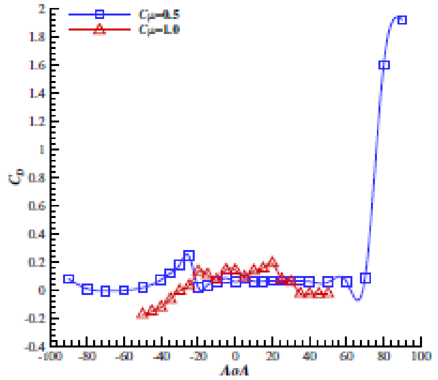
$$C_{Thrust} = C_L \cdot \cos AoA + C_D \cdot \sin AoA$$

➢Time-Averaged C_L, C_D, P_C and C_{Thrust} VS AoA:

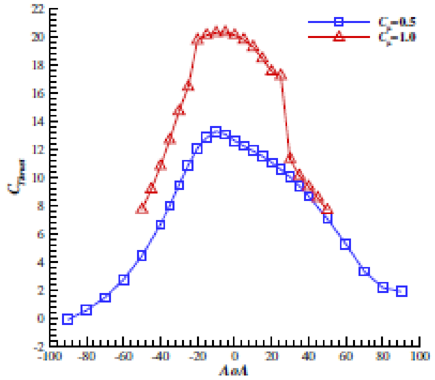
CFJ wind sails can tolerate wind direction variation range of -40deg to 20deg without substantial lift drop.



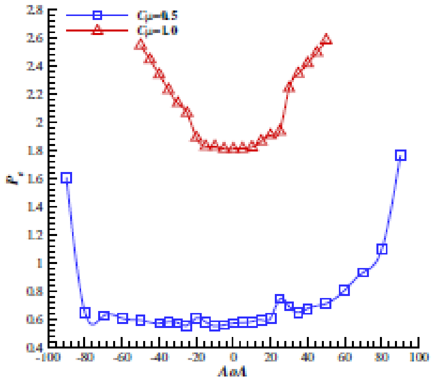
(a) Lift Coefficient.



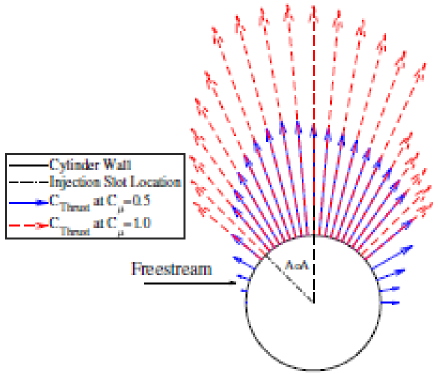
(b) Drag Coefficient.



(c) Thrust Coefficient.



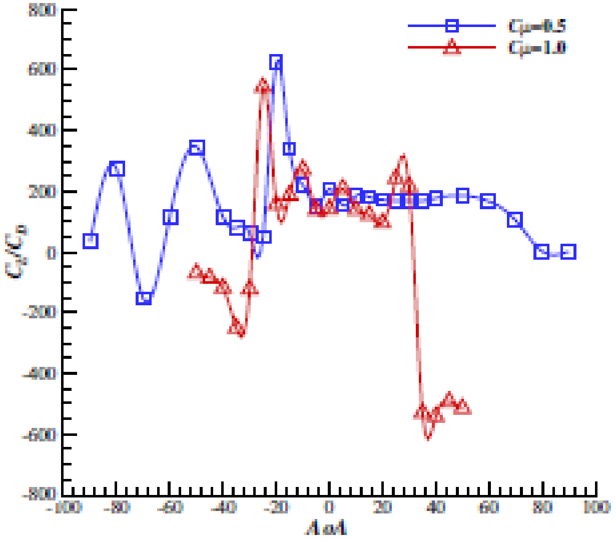
(d) Power Coefficient.



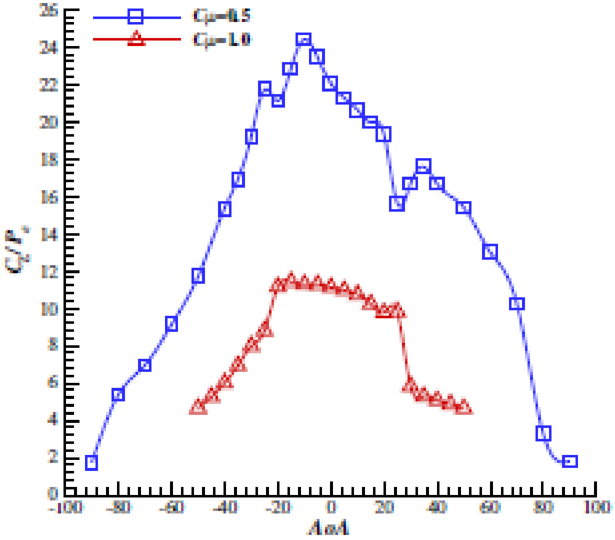
(e) Sketch of C_{Thrust} magnitude.

Sketch of C_{Thrust} magnitude

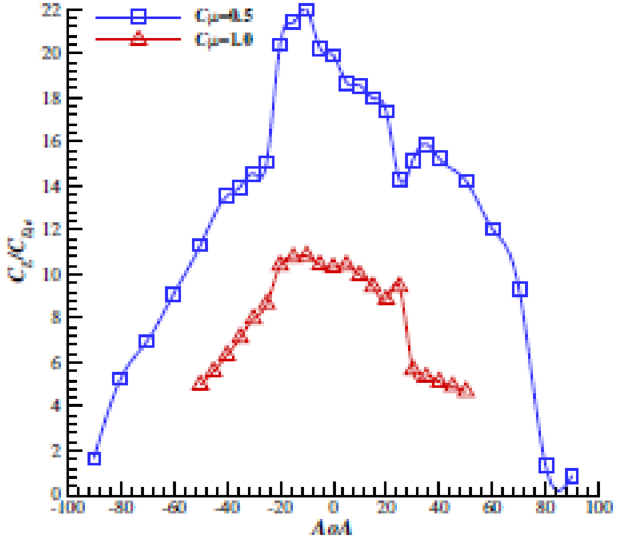
➢ Time-Averaged C_L/C_D, C_L/P_c and $C_L/C_{D,c}$ vs AoA



Lift-Drag Ratio



C_L/P_c



Corrected C_L/C_D

BENEFITS OF CFJ STATIONARY CYLINDERS: HIGH THRUST, SIMPLE AND LOW COST

- 20%-50% fuel reduction for large cargo ships
- Propulsive power increase > 100%
- Ultra-high thrust (>2X), CL ≥ 15
- 60-95% wind power for mid/small size cargo ships
- Simple system with no rotating structures
- Compact for all ship sizes
- Very low power required
- Low cost of manufacturing/maintenance
- Retrofitting
- Ideal for fully electric ships

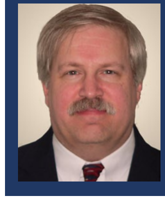
LEADERSHIP TEAM

Dr. Gecheng Zha | President, Professor, World Top 2% Scientist, NASA NIAC Fellow

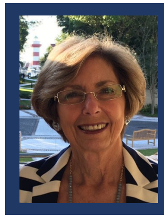
Dr. Yan Ren | Chief Technology Officer

Hagen Ruff | Vice President

Renee Lopez-Cantera | Advisor in PR



Donald Bingaman | Advisor in Aero Tech



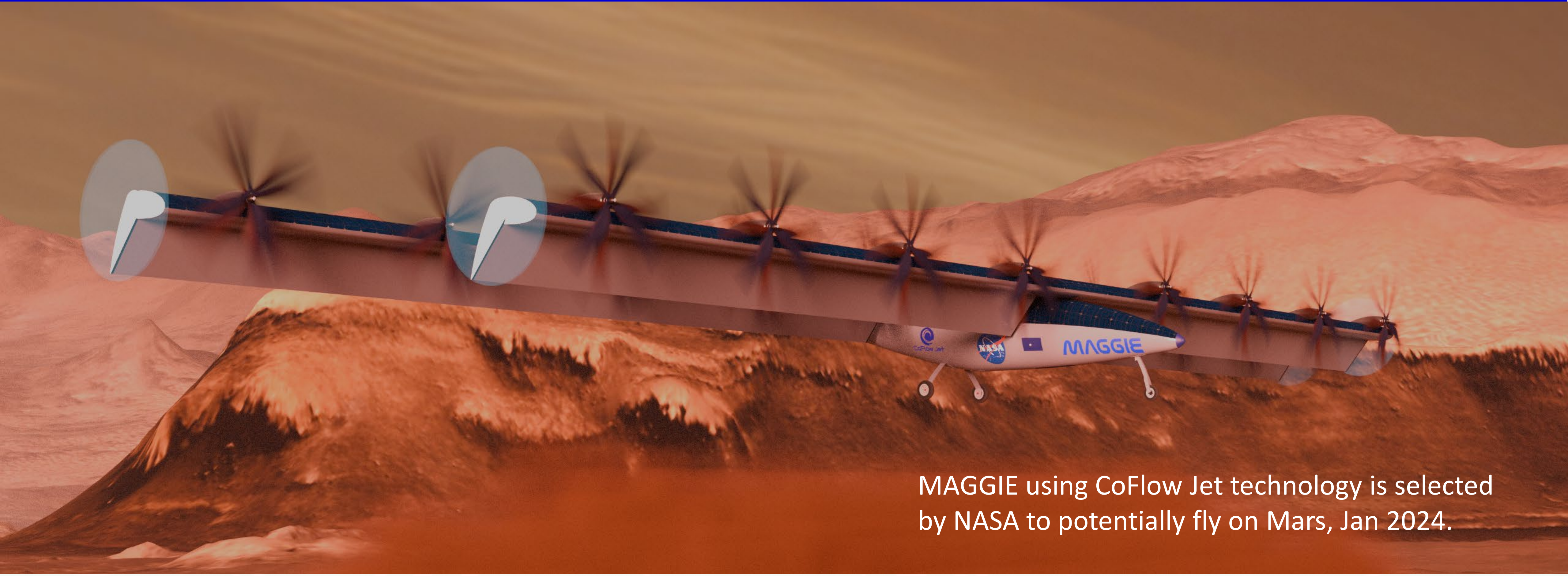
Nancy Bailey | Advisor in Brand Licensing

Syed Biabani | Advisor, Business Development

Chris Piedmonte | Advisor, Business Strategies

OUR FRONTIER IS BEYOND INFINITY

Transforming Marine Propulsion



DARPA | NASA | NSF | AFRL THE AIR FORCE RESEARCH LABORATORY LEAD | DISCOVER | DEVELOP | DELIVER | SCIENCE TO SHAPE THE FUTURE OF THE ARMY ARMY RESEARCH OFFICE 1951 | EBPT | CIRA | U | RICE ALLIANCE CLEAN ENERGY ACCELERATOR

THIRD DERIVATIVE | RMI ENERGY. TRANSFORMED. | NEW ENERGY NEXUS | PAN AMERICAN FINANCE