Ultra-High Efficiency Coflow Jet Airfoil and the Transformative Aircraft


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Airfoil: The fundamental element of aircraft

- Little airfoil development since 1960’s supercritical airfoil.
- Recent focus more on 3D airframe & airframe-propulsion integration.
- Have we reached the airfoil performance limit?

Sir George Cayley Bt. (1773 - 1857)
Father of Aeronautics

Airfoil mimicked from dolphin

Ultra-High Efficiency due to LE Super-Suction

7145 miles/9 days, nonstop

The Secret of Nature: Bird Wings Generate Super-Suction (Low Pressure) at Leading Edge.

Learn from Nature.

No Stall at AoA ~ 70°
Conventional Aircraft Problems

1) High Drag

2) Low Lift

B737 Flaps

3) Stalled

$\mathbf{v}_1$, $\mathbf{v}_2$
The Solution: CoFlow Jet (CFJ) Airfoil: Revolutionary Aviation Technology

Working Mechanism

• Small amount of flow sucked in at tailing edge.

• Energized by Micro-Compressor embedded inside.

• Injecting tangential jet from leading edge.

• Generating leading edge super-suction effect with low pressure drag or thrust, ultra-high lift coefficient.

• Overcome ultra-high adverse pressure gradient with no flow separation, virtually stall free.
Wind Tunnel Experiment Verification for NACA6415 Airfoil

PIV, reversed velocity deficit generating thrust, AoA = 25°

Wind Tunnel CFJ Provided by External Air Source

AoA = 25°
Baseline Airfoil Flow Separation

AoA = 25°
CFJ Airfoil, No Flow Separation
Ultra-High Lift, Low Drag, Low Energy Expenditure, Wind Tunnel Results with separated high pressure and low pressure source, 2015

Wind Tunnel Test Results

Comparison of the tested lift coefficient for baseline NACA0025 and CFJ0025-065-196 airfoil

Lift vs Angle of Attack

Drag polar, Thrust generated
CFD prediction compared with the measurement

Lift coefficient

Power coefficient

CL predicted well, except near stall

Power coefficient predicted very well
CoFlow Jet (CFJ) Airfoil: Superior Performance:

- Superlift Coefficient ($C_L > 8$)
- Ultra-high Cruise Productivity Efficiency ($C_L^2/C_D$)
- Dramatically Reduce Pressure Drag (or generating thrust)
- Low Energy Expenditure
- Zero-net Mass-flux Flow Control
- Ultra-High Safety (Stall free)
- Flapless High Lift System
- Extremely short takeoff/landing Distance
- Very Quiet with Low Noise

Superior Performance:

$$V_\infty, \quad CL=10.6, \quad C_{mu}=0.35, \quad M=0.087, \quad AoA=70\text{deg}$$
Vorticity distribution for CFJ airfoil at AoA=70°, $C\mu=0.35$

CFD

Wind Tunnel

CCW rollup

CFJ $C\mu=0.020$
Wind Tunnel Testing with Embedded Micro-Compressors (11/2017), DARPA Project CFJ-NACA-6421 Airfoil,
Study of 3D Induced Drag at Ultra-High Lift (CFD)

- AoA = 70°
- $C_\mu = 0.25$
- $CL = 7.26$
- AR=20
Wingtip vortex

• Wing vortex layer and tip vortex

Tip vortex core

Low pressure at tip vortex core
Oswald efficiency $e_0$ calculation

$C_\mu = 0.15, 0.25; \ AR = 5, 10, 20$

- CFJ wing generate Negative $C_{D0}$ (thrust) at zero-lift condition
- Oswald efficiency $e_0 \in [0.73 - 0.97]$
- Induced drag $C_{Di} = C_D - C_{D0}$ decreases with $AR$

$$e_0 = \frac{C_L^2}{(C_D - C_{D0}) \pi AR}$$
Drag Polar Data and Oswald efficiency $e_0$

- $C_\mu = 0.15, 0.25$
- AR = 5, 10, 20

$$e_0 = \frac{C_L^2}{(C_D - C_{D0})\pi AR}$$

<table>
<thead>
<tr>
<th>$C_\mu$</th>
<th>AR</th>
<th>AoA</th>
<th>$C_L$</th>
<th>$C_D$</th>
<th>$P_c$</th>
<th>$C_{D0}$</th>
<th>Oswald efficiency $e_0$</th>
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<td>70</td>
<td>7.26</td>
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<td>2.818</td>
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<td>0.726</td>
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Transonic CFJ airfoil study 2: Regular CFJ with injection at leading edge. CFJ RAE2822 Airfoil Improves Transonic Cruise Lift & Efficiency.

Peak efficiency improved by 14.7% and lift coefficient improved by 18% at the same time. Productivity Efficiency $\frac{CL^2}{CD}$ increased by 36%.
Transonic CFJ Airfoil study 2: RAE2822 airfoil with injection at leading edge
Transonic CFJ Airfoil study 2: RAE2822 airfoil with injection at leading edge
First Product: CFJ-Seagull, a Distributed Electric Propulsion CFJ GA Airplane, 4 seats, range=512km (2X of SoA), Cruise Speed=186km/h, Wing Span=14.9m, Weight=1896kg, Wing Loading=182.3 kg/m2.
Electric Airplane: Aviation’s New Wave

Advantages:
- High Energy Efficiency
- Low Emission
- Low Noise
- Suitable for General Aviation (GA)

Large Market (US):
- US has over 15000 under-utilized GA airports
- 95% US population live within 15 miles to a GA airport
- 50% Travelers’ Distance <500Miles
- Annual market value near hundreds of billions US Dollars
Competitors, USA

Larry Page’s Zee Aero and Kitty Hawk electric airplane

Joby Aviation Electric GA, CA, 2 Seats, Range=321km, V=300km/h, VTOL

An early prototype of Joby’s flying car, Future vehicles will seat four and look more planelike, with six propellers positioned around the craft.

ILLUSTRATIONS BY ARMANDO VEVE; DATA COMPILED BY BLOOMBERG
Competitors, Europe

Air Bus E-fan, Electric Trainer, 2 Seats, Range=150km, V=160km/h

Linium, Electric GA, 5 Seats, Range=300km, V=300km/h, VTOL

Liaoning/Ruixiang RX1E, 2 Seats, Range=200km, V=110km/h

- Delivery to market in 2025,
- Received $90M Investment led by Tencent (腾讯), Sept. 2017
State of the Art (SoA) Electric General Aviation (E-GA) Airplanes


4 passengers, range=250nm, wing span=21.36m, CL=0.50, L/D=28, W/S=69.6kg/m²

e-Genius, EA, broke 7 world records, July 2014.

2 passengers, range=216nm, wing span=14.56m, CL=0.57, L/D=26, W/S=61.8kg/m²

Shortcomings of Current E-GA

- Low Energy Density of Batteries
- Large Size
- Short Range
CFJ-Seagull: Whole aircraft 3D CFD Simulation and Design, Mach Contours
## Comparison of CFJ-Seagull with SoA Aircraft

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Cessna 172</th>
<th>E-Genius</th>
<th>Taurus G4</th>
<th>CFJ EA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing span (m)</td>
<td>11</td>
<td>16.9</td>
<td>21.36</td>
<td>14.9</td>
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<tr>
<td>Planform area (m²)</td>
<td>16.2</td>
<td>14.56</td>
<td>20.30</td>
<td>10.44</td>
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<tr>
<td>Aspect ratio</td>
<td>7.3</td>
<td>19.6</td>
<td>22.5</td>
<td>21.3</td>
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<tr>
<td>Passengers</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
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<tr>
<td>Cruise $C_L$</td>
<td>0.32</td>
<td>0.57</td>
<td>0.5</td>
<td>1.31</td>
</tr>
<tr>
<td>Cruise $(L/D)_C$</td>
<td>7</td>
<td>26</td>
<td>28</td>
<td>23.5</td>
</tr>
<tr>
<td>Cruise $(C_L^2/C_D)_C$</td>
<td>2.24</td>
<td>14.82</td>
<td>14</td>
<td>30.78</td>
</tr>
<tr>
<td>Takeoff weight (kg)</td>
<td>1111</td>
<td>950</td>
<td>1496</td>
<td>1896</td>
</tr>
<tr>
<td>Battery weight (kg)</td>
<td>N/A</td>
<td>310.0</td>
<td>500.0</td>
<td>792.6</td>
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<tr>
<td>Structure factor</td>
<td>0.69</td>
<td>0.47</td>
<td>0.39</td>
<td>0.39</td>
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<tr>
<td>Wing loading (kg/m²)</td>
<td>68.6</td>
<td>61.8</td>
<td>69.6</td>
<td>182.3</td>
</tr>
<tr>
<td>Range (nm)</td>
<td>700</td>
<td>216</td>
<td>250</td>
<td>314</td>
</tr>
<tr>
<td>MPS (Miles*Passengers/S)</td>
<td>172.8</td>
<td>29.7</td>
<td>49.3</td>
<td>120.8</td>
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<tr>
<td>Total cruise power (kw)</td>
<td>251.6</td>
<td>17.6</td>
<td>32</td>
<td>46(Prop=35.7; CFJ=10.34)</td>
</tr>
<tr>
<td>Takeoff distance (m)</td>
<td>519</td>
<td>519</td>
<td>610</td>
<td>610</td>
</tr>
</tbody>
</table>

Increase range by 2 times for the same size E-GA
Leadership Team

Dr. Gecheng Zha,
President, Professor,
AIAA Associate Fellow,
ASME Fellow,
NASA NIAC Fellow,
CFJ Inventor,
Worked at GE, PW,
USAFRL, Funded by
DARPA, NASA,
AFOSR, ARO, etc.

Mr. Patrick J. Sheppard
VP/Corporate Secretary,
Accomplished entrepreneur and
founders of multiple very successful energy
technology companies.
Help to decide the
comppany development
strategy and direction.

Dr. Joseph Johnson
Director, Associate Professor.
Specialized in new Product
Development, Marketing
Strategy, Extensive
Industrial Experience
Mr. Peter Trogos,
Director, Extensive experience with Aerospace Industry in Marketing, Sales and Business Development. Worked with Dassault, Boeing, Airbus, Gulfstream, Mathworks, etc.

Mr. Gary Pridgen, CFO, CPA
Serves as financial consultant and management team member for several developing technology companies. He was formerly president of Voyager Insurance Companies, a public company later acquired by a Fortune 500 company.
Advisory Board

Ms. Renee Lopez-Cantera
Marketing and PR Adviser, VP of Business Development at Eikon Digital, dedicated community activist, executive board member of multiple organizations, recipient of Knight Foundation scholarship for Women in Tech 2017.

Mr. Dorald Cummings,
Technical Advisor, retired Boeing Technical Fellow, 50 years experience in aircraft design and development, winner of the 2015 AIAA Aircraft Design Award.
**Engineering Team:** Talented Young Enthusiastic Engineers led by Dr. Yan Ren and Mr. Yunchao Yang (PhD Candidate).
Competitive Advantages:

(1) **Long Range**: Based on 2025 market prediction, CFJ-Seagull will be the only E-GA with range greater than 500km and compact size.
(2) **Ultra-High Efficiency**: Save battery or fuel energy consumption
(3) **Low Emission**: Reduce life cycle emission by 75%.
(4) **Low Operating Cost**: energy cost only $0.05/km.
(5) **Compact Size**: Easy operation in small airports and storage
(6) **Flight Comfort**: Ultra-high wing loading reduces atmospheric disturbance
(7) **Owns IP, Patents, and CFJ inventors.**
(8) **In house CFD aircraft design and simulation software.**
(9) **Dedicated and Committed Team**
## CFJ-Seagull Development Timeline and Investment Outlay

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time Line</th>
<th>Milestones</th>
<th>Budget/Company Share</th>
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</thead>
<tbody>
<tr>
<td>I, 36months</td>
<td>2018-2020</td>
<td>Unmanned prototype flight demonstration</td>
<td>$12M.</td>
</tr>
<tr>
<td>II, 36 months</td>
<td>2021-2022</td>
<td>Manned prototype flight demonstration, FAA certification and product delivery to market</td>
<td>$TBD</td>
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</table>
## COMPANY TEN-YEAR PROJECTION OF REVENUES

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
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</thead>
<tbody>
<tr>
<td>Demand ($Billion)</td>
<td>75</td>
<td>82</td>
<td>95</td>
<td>100</td>
<td>102</td>
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</tbody>
</table>

**US GA and Light Aircraft Demand Trend**

6 Years Break Even
Business Model

1) Profit from IP and Patents Licensing to E-GA, GA, Drone Manufacturers.

2) Start with US Market, then Penetrate to Europe and Asian Markets

3) Start with E-GA, then Expand to Transonic transports, amphibious aircraft, rotorcraft, vertical takeoff/landing aircraft.
Business Risks:

- Sensitive to Economy Situation and Cycle
- IP fee Competitive
- Reversed Engineering and IP Protection

All above are addressed with business solutions.
Technology Risks:

- Micro-Compressor Performance
- System Integration
- Batteries Heat Management
- All Weather Flight

All above are addressed with technical solutions
Collaboration and Investment welcomed.

Contact: gzha@Miami.edu
Coflowjet.com