

The Promise of Electric STOL: eSTOL

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IDEAL eSTOL

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Themes of this Presentation

- While eVTOL is the holy grail, it is limited.
- eSTOL is understudied and may prove to be competitive with eVTOL, especially after the side-walk ends.
- Propulsion-Airframe Interaction (PAI) may be key to eSTOL and, it too is understudied.

My background

- BS and MS in aerospace engineering (1960s)
- Transonic wind tunnel work for the Navy (1960s)
- Air Force Flight Dynamics Lab (1970s)
- Emeritus Professor of product design (1980-2005)
 - Text “*The Mechanical Design Process*” 6th edition
 - Life Fellow ASME
- Built two general aviation airplanes
- Electric airplane design (2009- present)

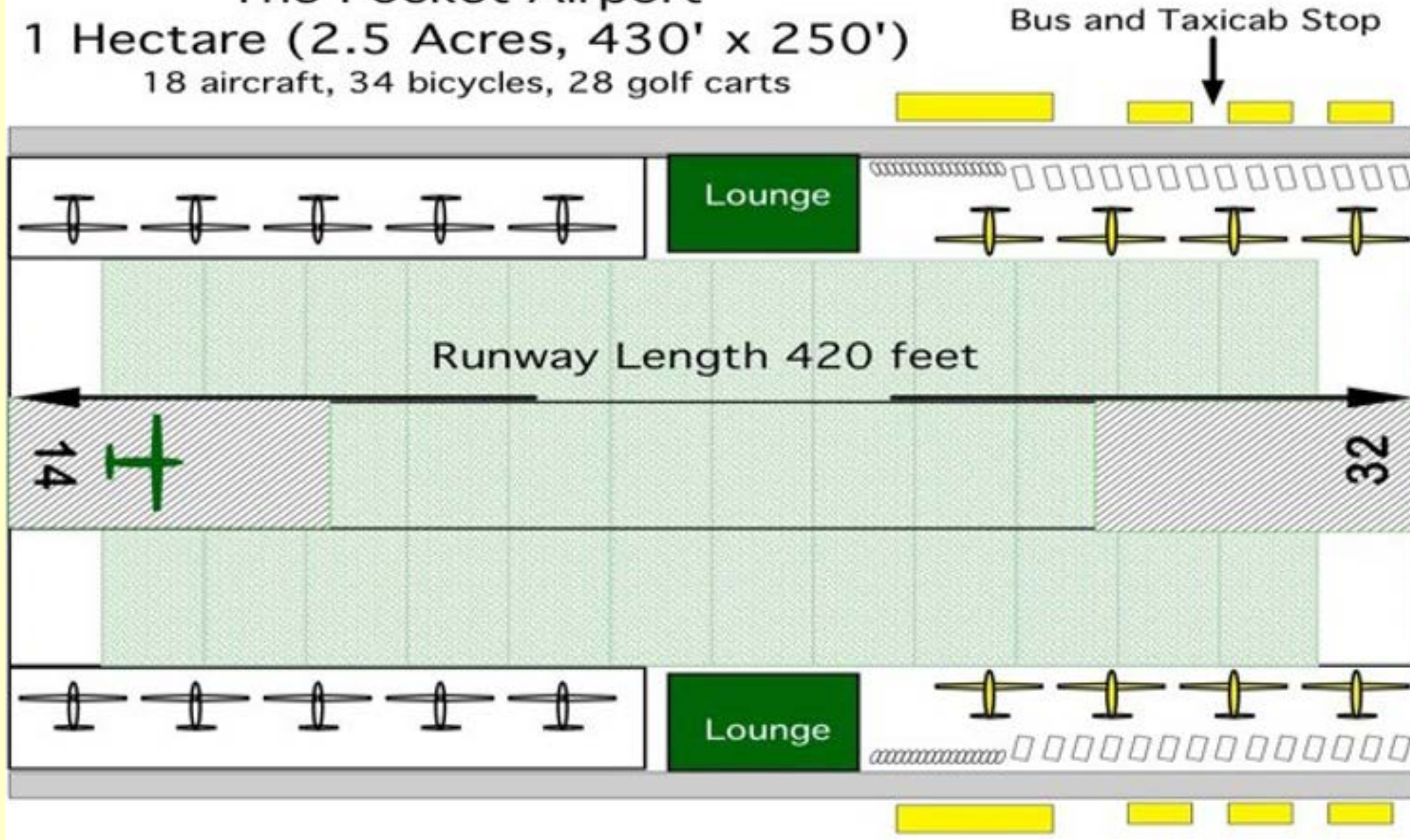


In a 2010 KitPlanes magazine article I made four, 5-year predictions.

- An electrically powered airplane will stay aloft for two hours carrying two people.
- An electrically powered airplane will be cost competitive for light-sport aircraft and trainers.
- Electric airplanes will be powered by batteries with energy densities at least 50 percent better than those available today.
- An electric airplane will land at an airport near you!

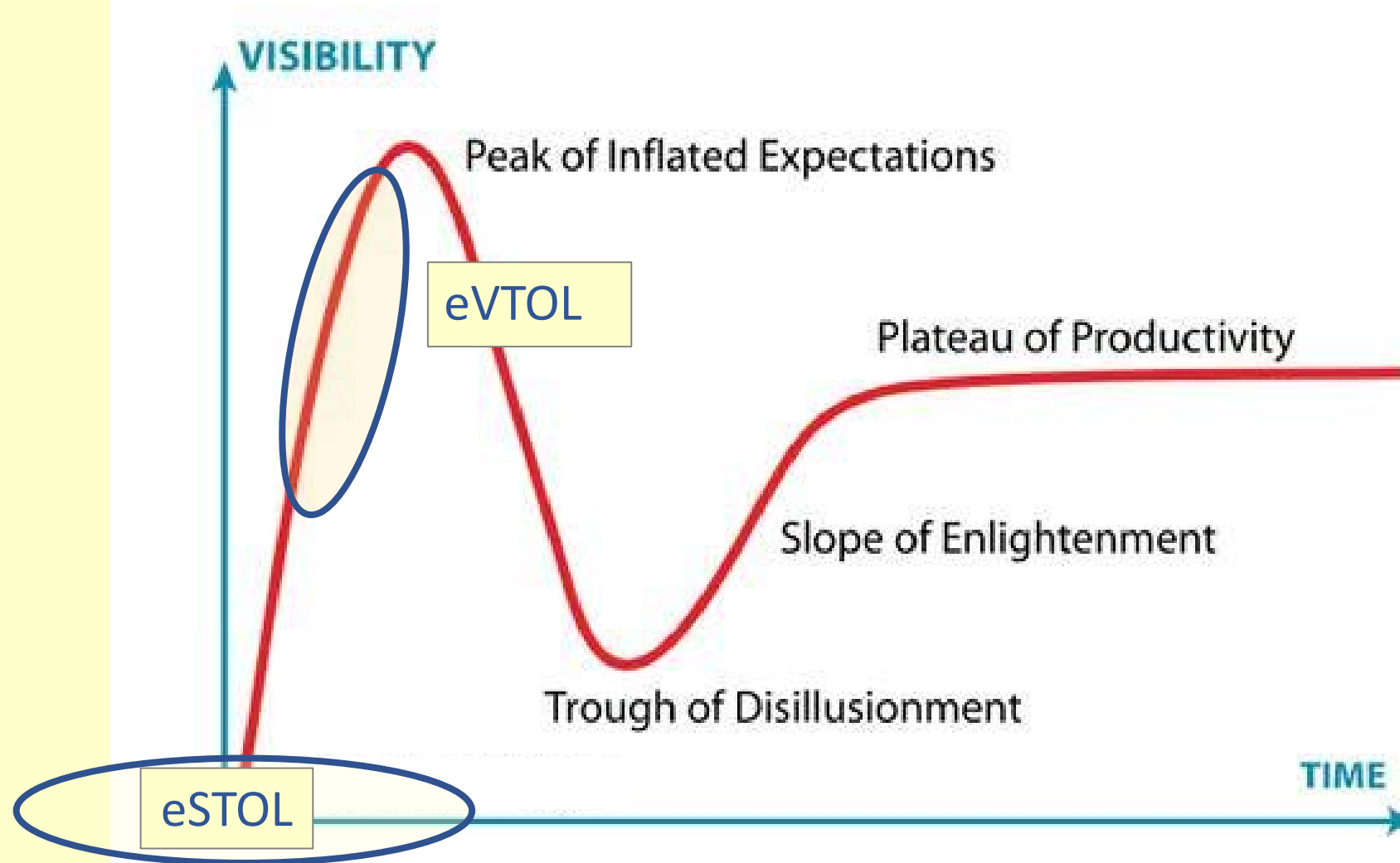
The Pocket Airport

1 Hectare (2.5 Acres, 430' x 250')
18 aircraft, 34 bicycles, 28 golf carts



131m x
76m

Gartner Hype Cycle



Many are focused on eVTOL, but what if eSTOL could take off and land in a very short distance, using much less power (less noise) and with greatly increased range?



The goal here is to see if eSTOL can rival VTOL and identify what is unique and its potential

- Start with the state of the STOL art – the Lil' Cub.
- Take off 14' 7" (4.4m)
- Landing 10' 5" (3.2m)
- Total score of 25' (7.6m)

This is BF-STOL
Brute Force-STOL



Take-Off Distance

$$S_g = \frac{13 * \frac{W}{A}}{\frac{T}{W} * CL_{TO}}$$

@ sea level

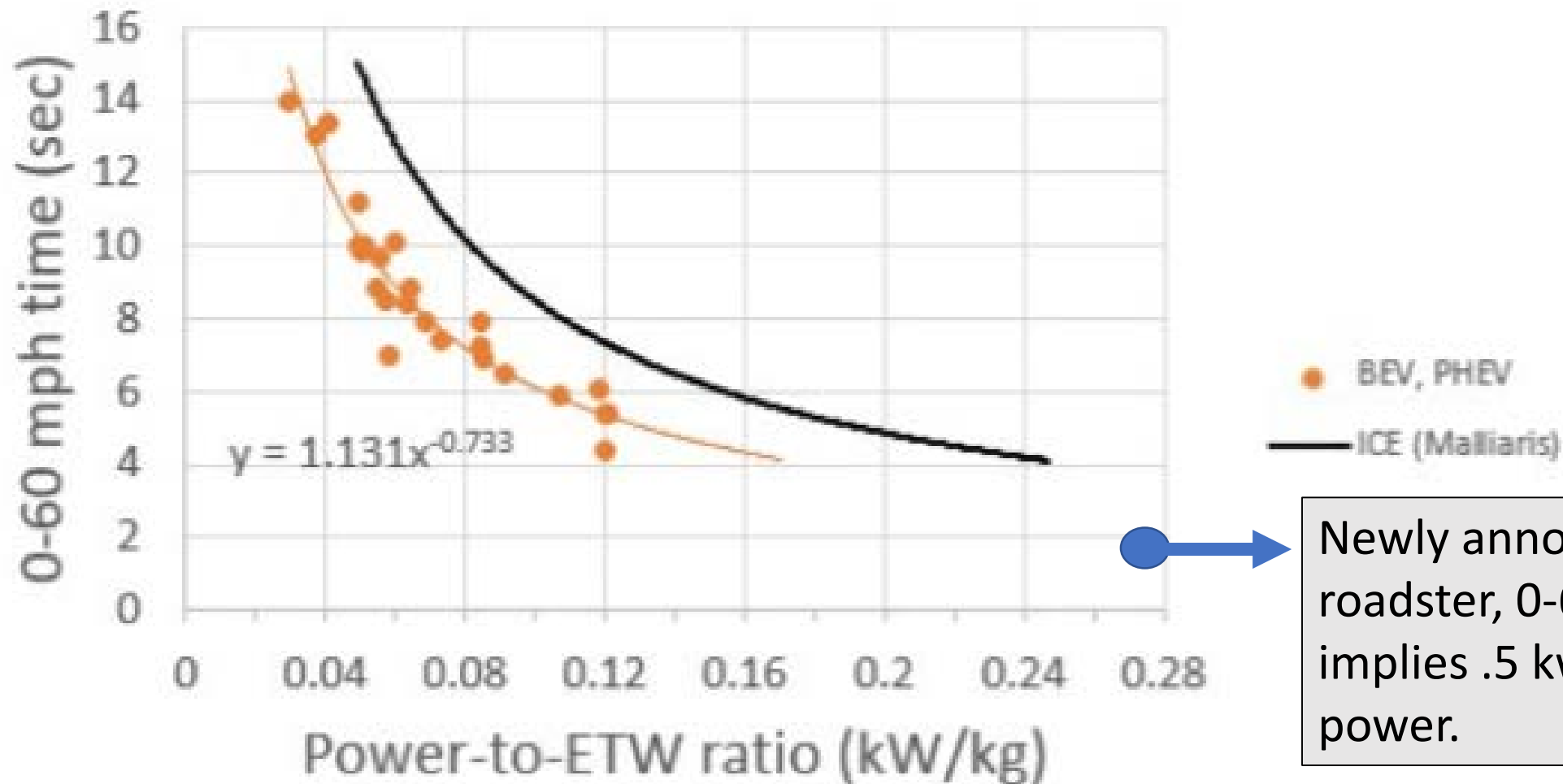
There are only 3 ways to shorten Take-off distance:

- Lower the wing loading (W/A) – low weight big wing. Cruise penalty.
- Raise the thrust to weight ratio (T/W)
- Raise the take-off lift coefficient CL_{TO}

Lil' Cub has:

- Large wing
- Low weight
- High thrust
- CL raised by cuff, flaps and deflecting the propwash on underside of the wing

One option for eSTOL is to put a very powerful electric motor with a very high thrust propeller



Newly announced Tesla roadster, 0-60 in 1.9 sec - implies .5 kw/kg specific power.

Thrust to weight ratio for VTOL

$$\frac{T}{W} \geq 1.15 \text{ (realistically 1.25)}$$

Thrust is proportional to Power

Power = Noise!

Low noise is a critical success factor

Take-Off Distance

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To Increase CL_{TO} Use DEP to create PAI

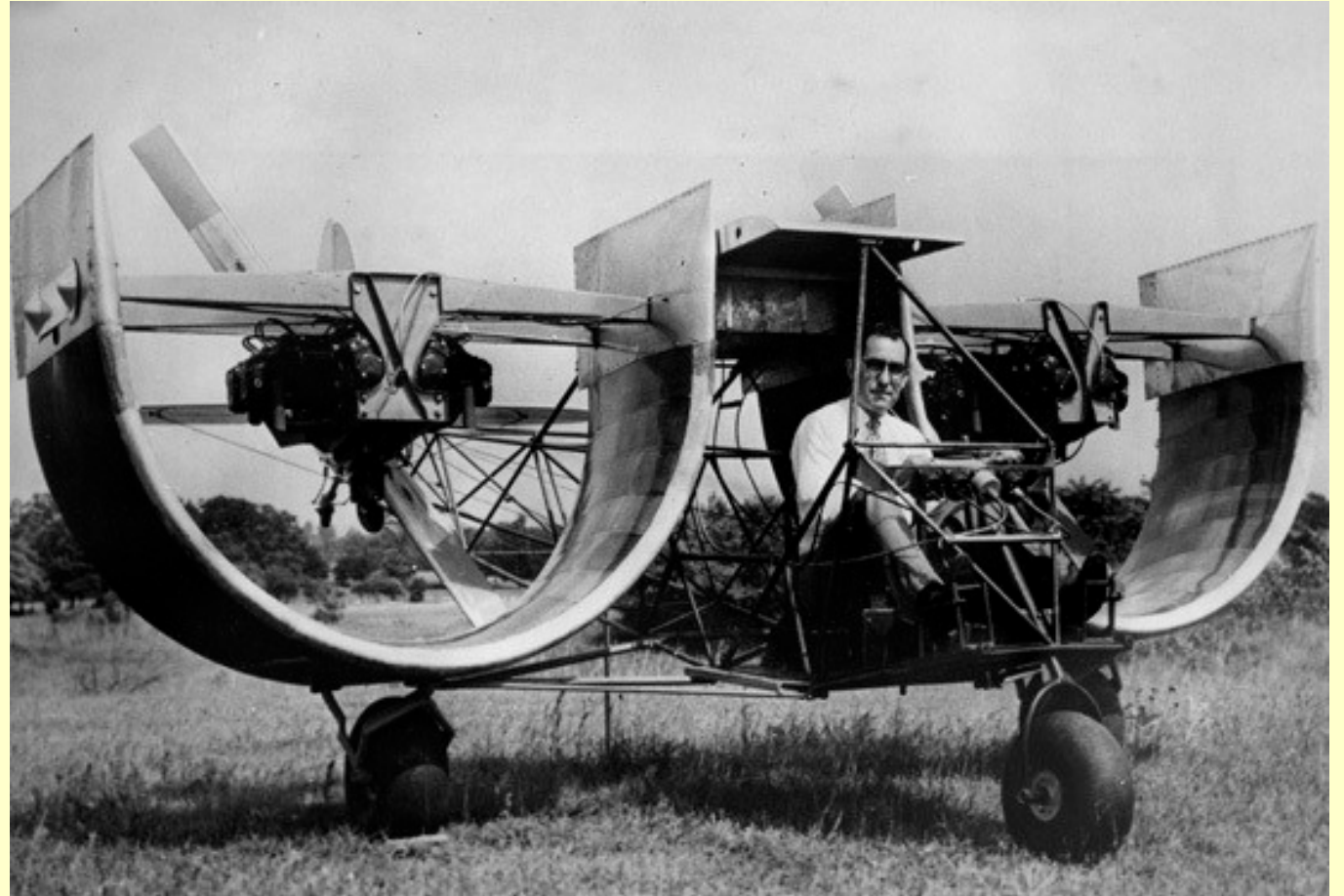
- DEP = **Distributed Electric Propulsion**
- PAI = **Propulsion-Airframe Interaction**
 - Use the air moved by the propulsor to gain aerodynamic advantages as it passes over the airplane's wings, fuselage and other surfaces.
 - This is not new but is not well studied for eSTOL.
- DEP makes it possible to mold the air accelerated by the propulsion in ways that a few large IC or turbine engine could not.
- The remainder of this presentation is on the history of one form of PAI, **Upper Surface Blowing**; its potential, and some details on one research project.

The Custer Channel Wing, CCW-2

- Willard Custer saw a barn door torn off by the wind and realizes:

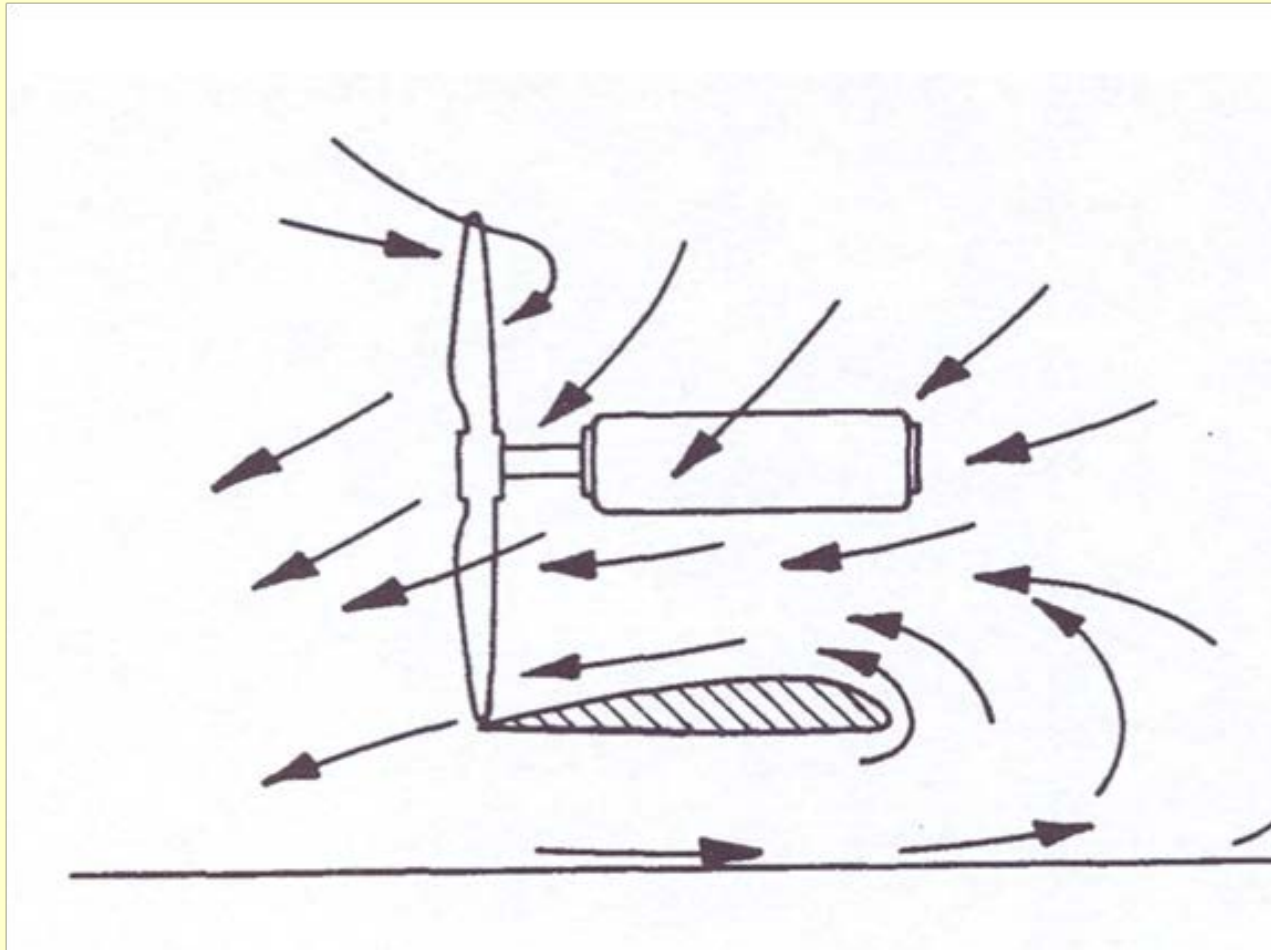
*"It's the speed of the
air,
not the airspeed."*

Willard Custer



1946

Custer Channel Wing: Static Air Flow



CCW-5



YC-14 used Upper Surface Blowing (USB) to achieve high Lift Coefficients



1967

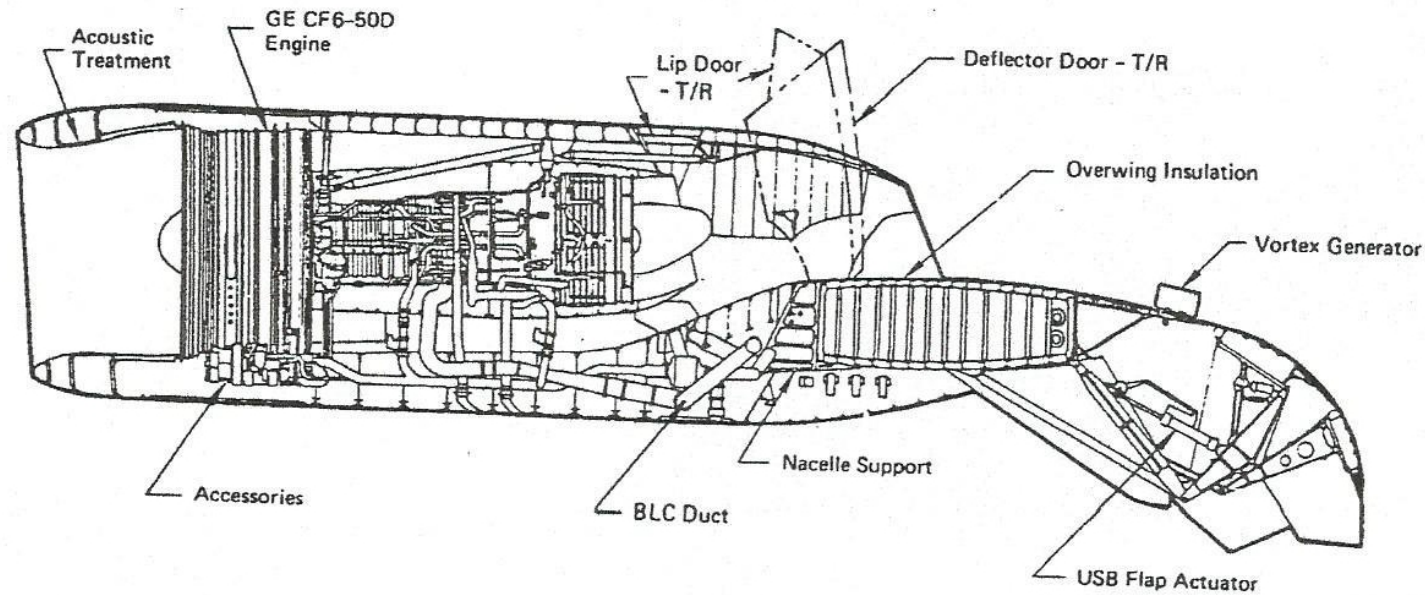


Fig. 21 Engine and nacelle cross section. Reprinted with permission from AIAA Preprint AIAA-74-972 © 1974.

The 170,000 pound (77,000 kg) GW YC-14 could take off and land in 800' (240m). Similar GW aircraft needed 2200' (650m).

QSRA 1987



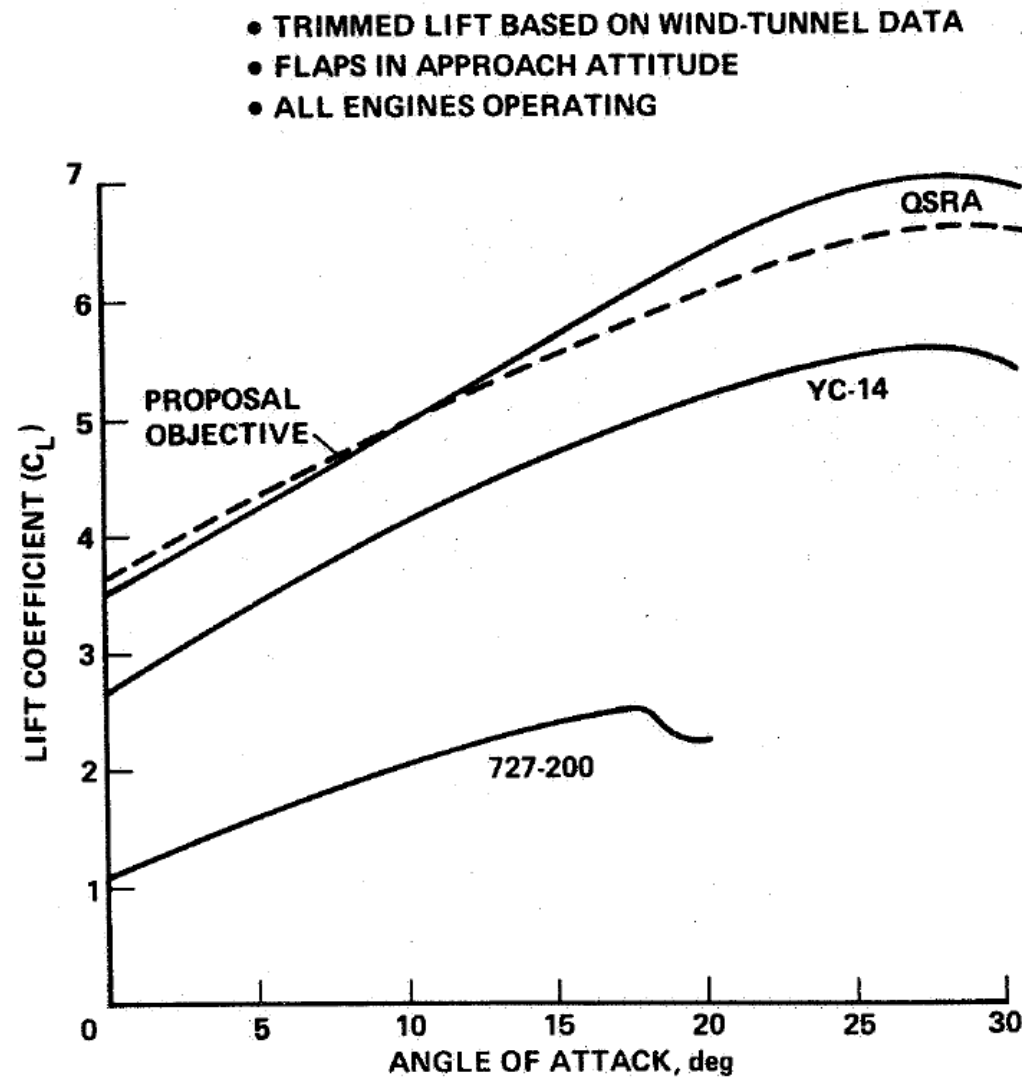
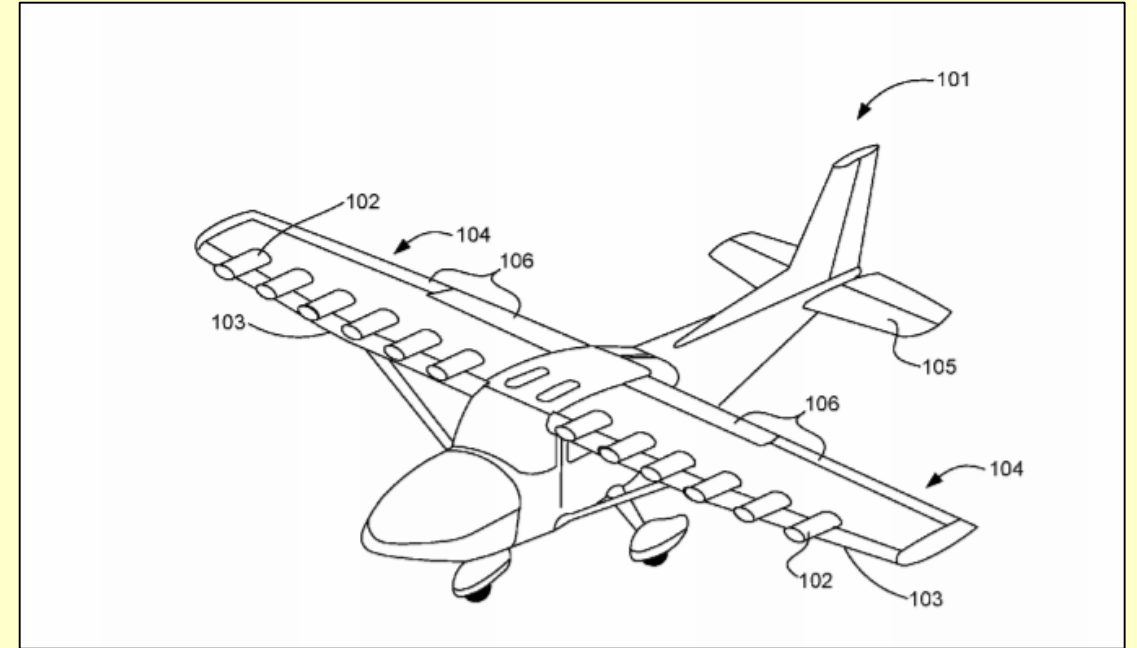


Figure 21. - Comparison of the powered-lift performance of the QSRA with a conventional transport and with an advanced STOL transport.

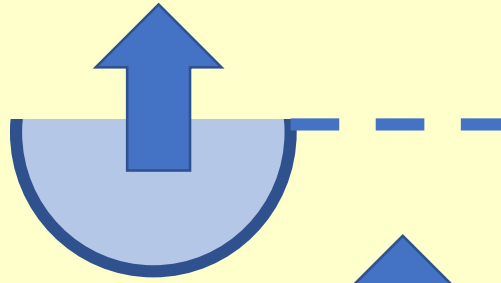
The IDEAL Project

- IDEAL = Integrated Distributed Electric-Augmented Lift
- Privately funded
- Five-year project begun in 2015 to explore the potential of PAI and its abilities at low speed and during cruise
- U.S. Patent #10,099,793, Distributed Electric Ducted Fan Oct 2018

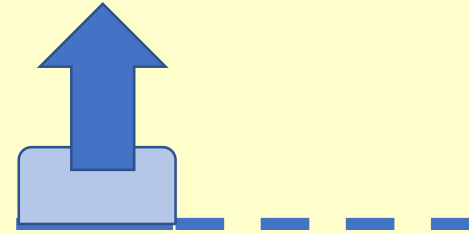


The Evolution of Propulsion-Airframe Interaction (PAI)

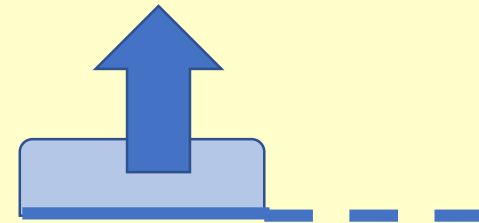
Custer used IC engines in channels



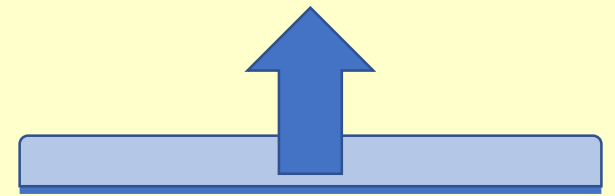
The YC-14 used two jet engines with exhaust spread span wise



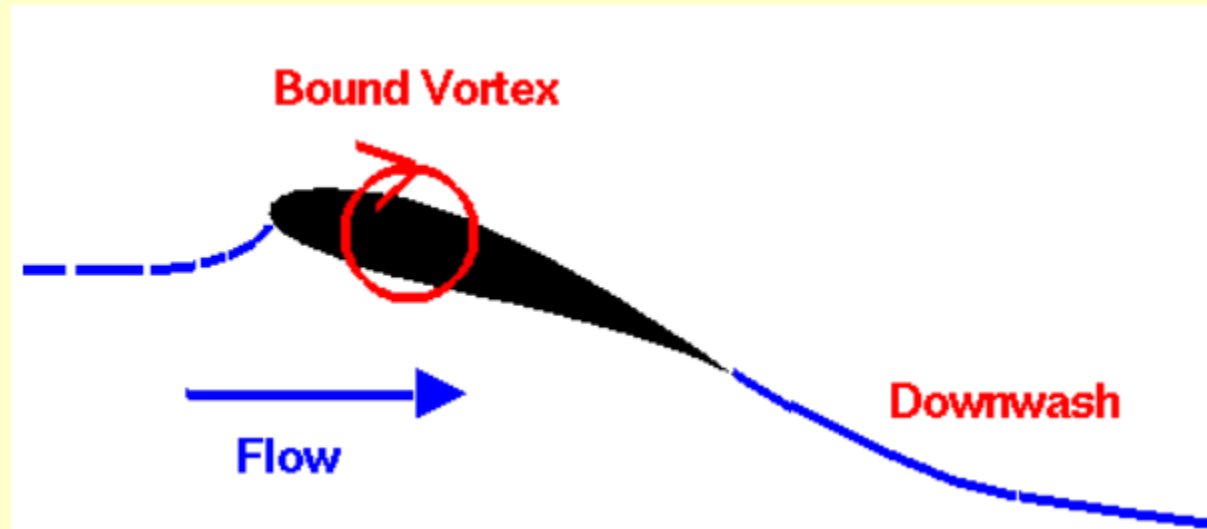
The QSRA used four jets further spreading high velocity air



IDEAL uses many distributed Electric Ducted Fans (EDFs) to generate Distributed Electric Propulsion (DEP) along the span



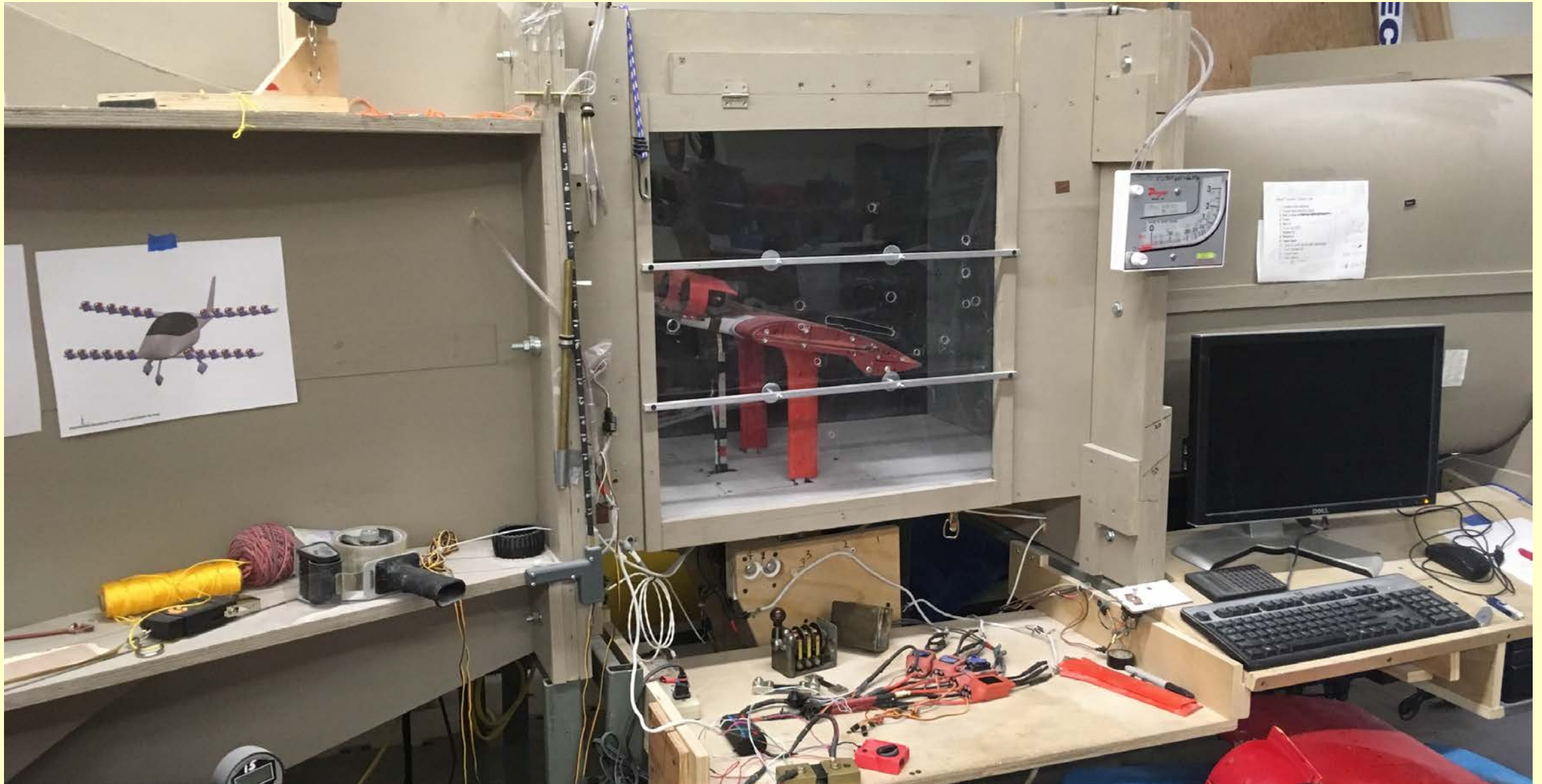
The Kutta-Joukowski theorem



$$C_L = C_1 + C_2 * (V_t/V_o)$$

- If we can double the velocity on the top surface of the wing, we virtually double the lift coefficient.
- While the equation seems overly simplistic, it is useful if it can be verified across multiple conditions through testing.

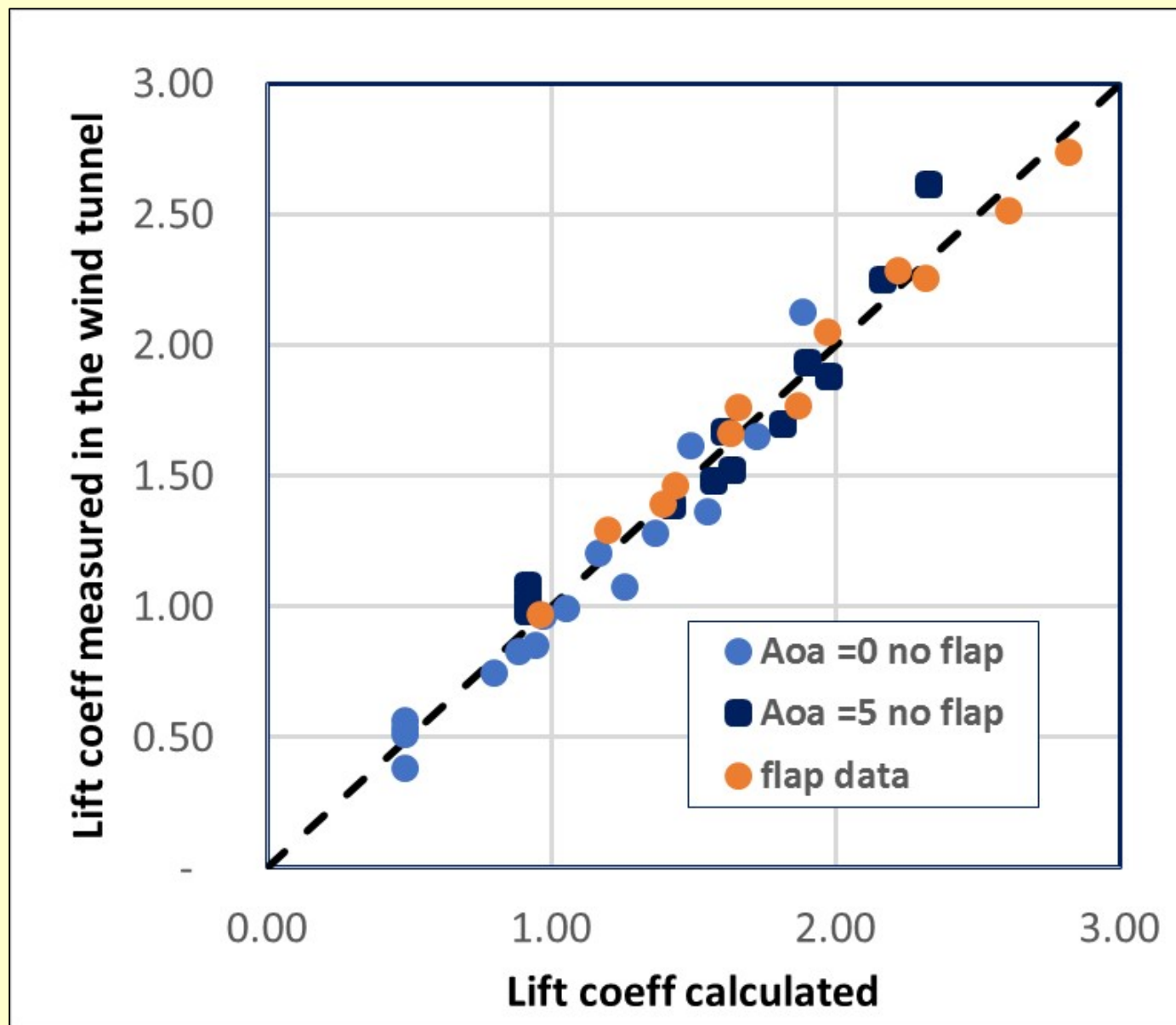






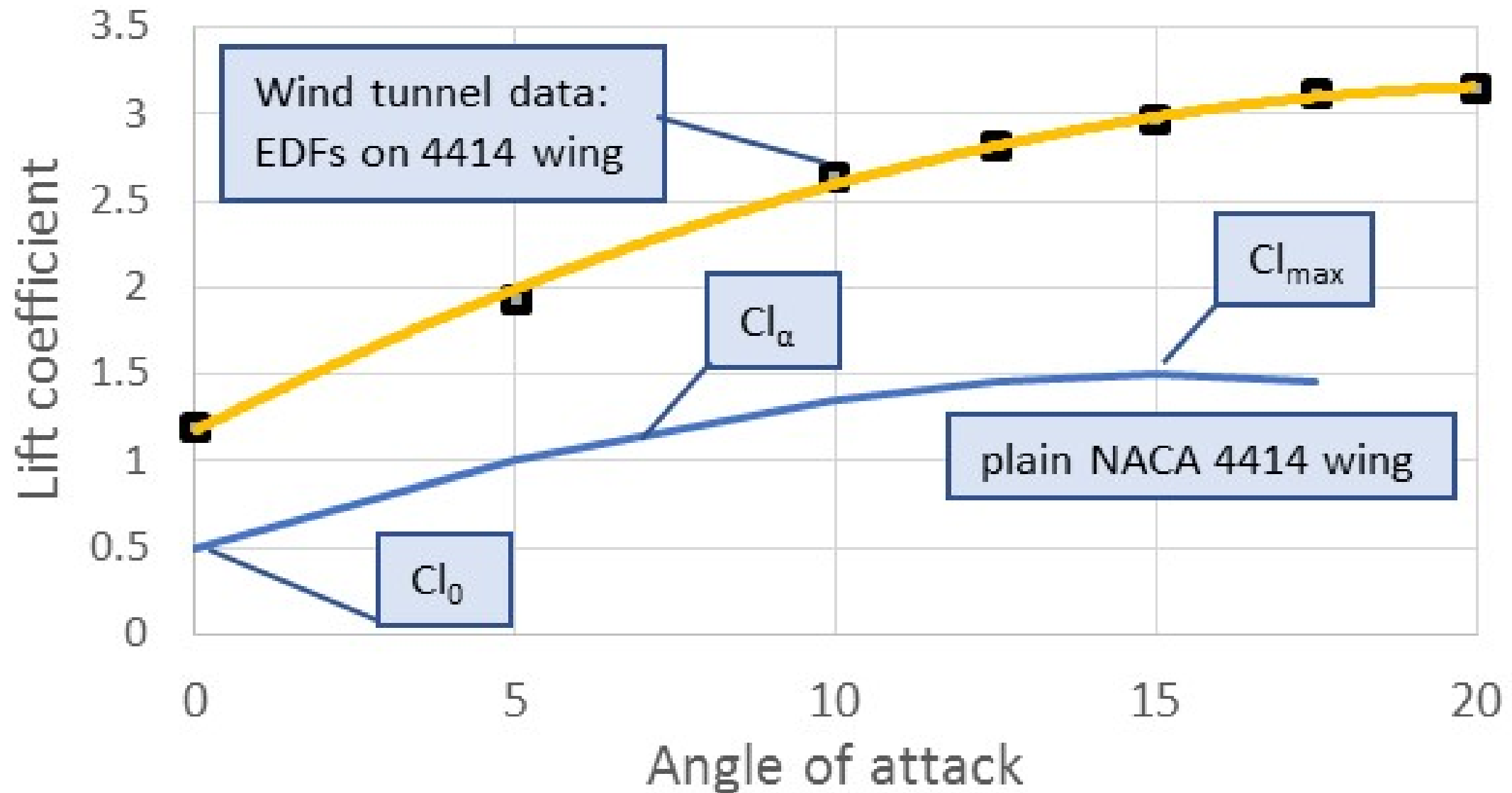
Design of Experiments Models to Find Optimum Configuration



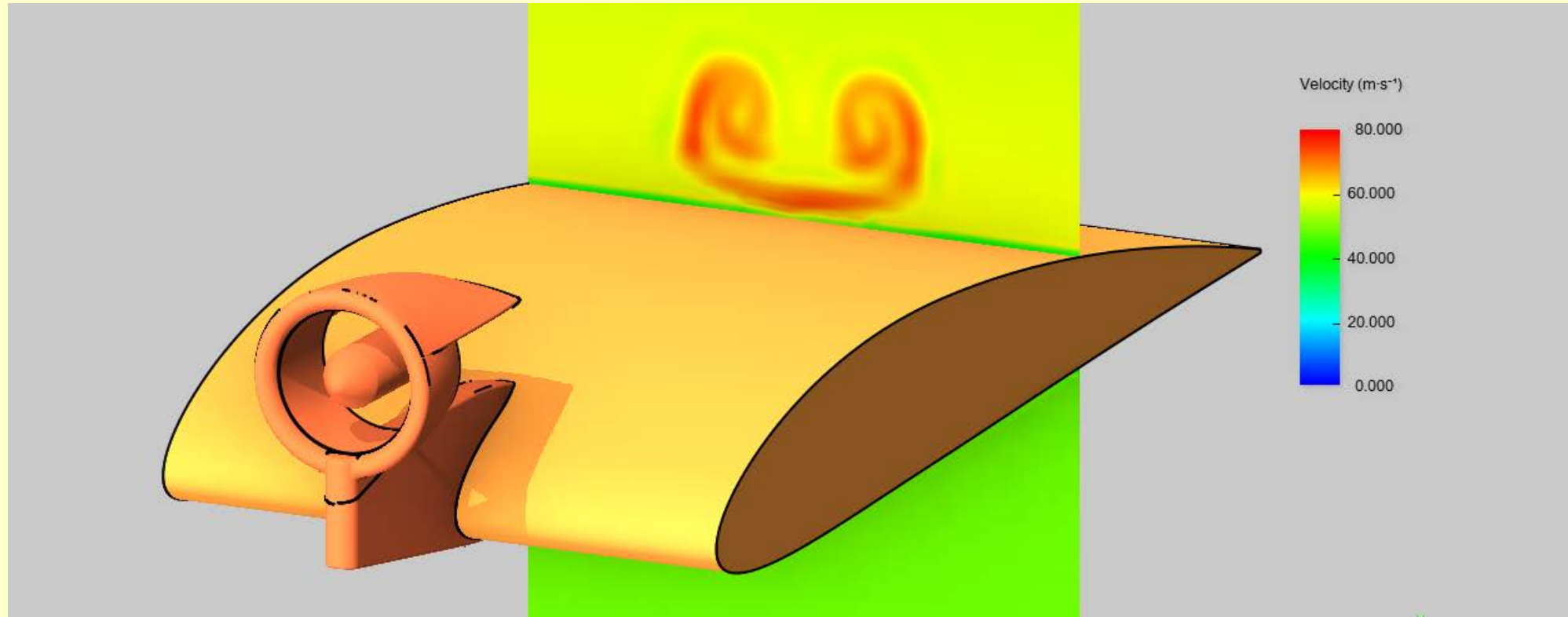


$$R^2 = .97$$

Lift Coefficient versus Angle of Attack



We have begun doing some CFD.

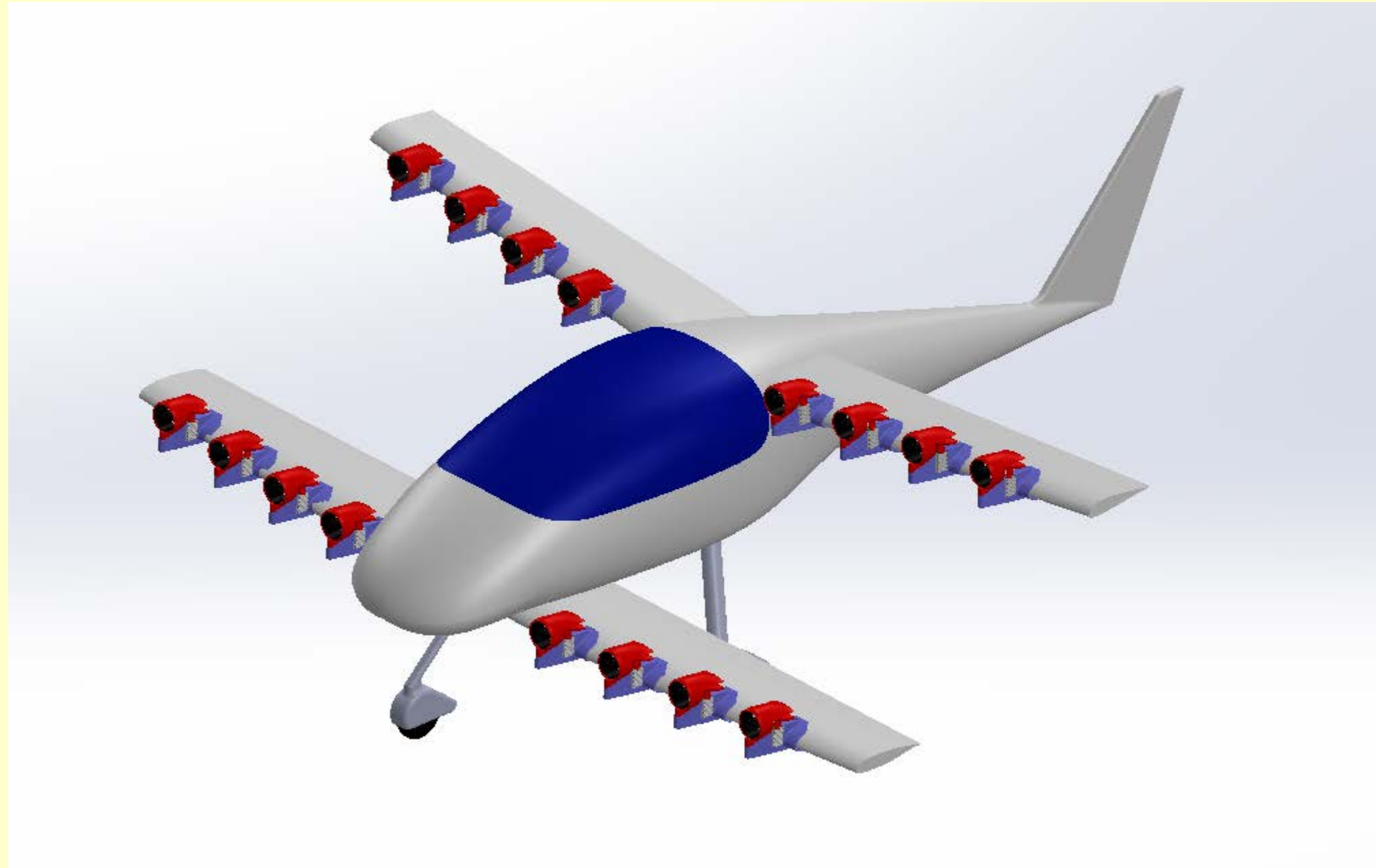


Thanks to Jac van Egmond of mvAERO for the CFD modeling

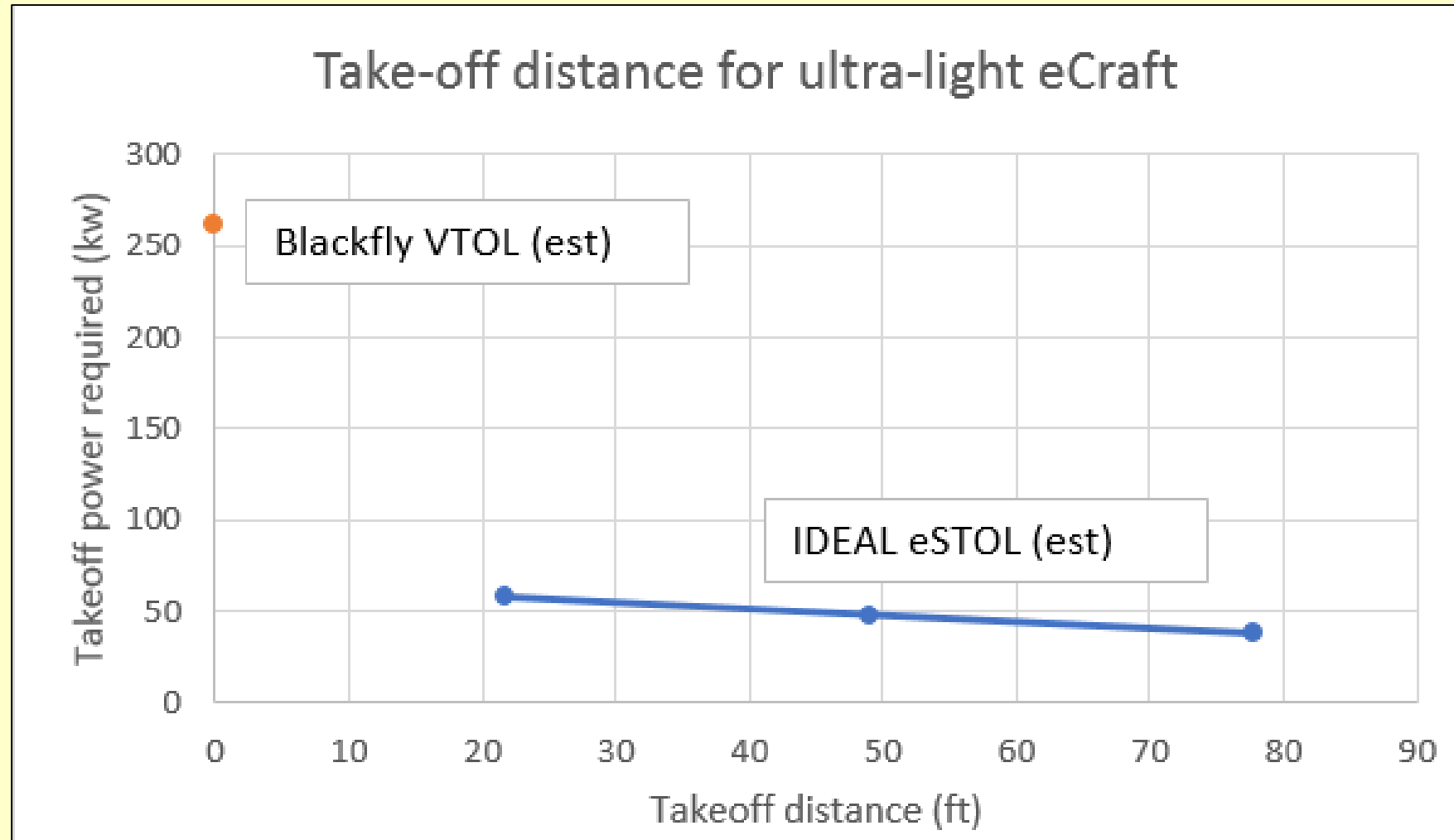
Flight testing with the JabirWatt

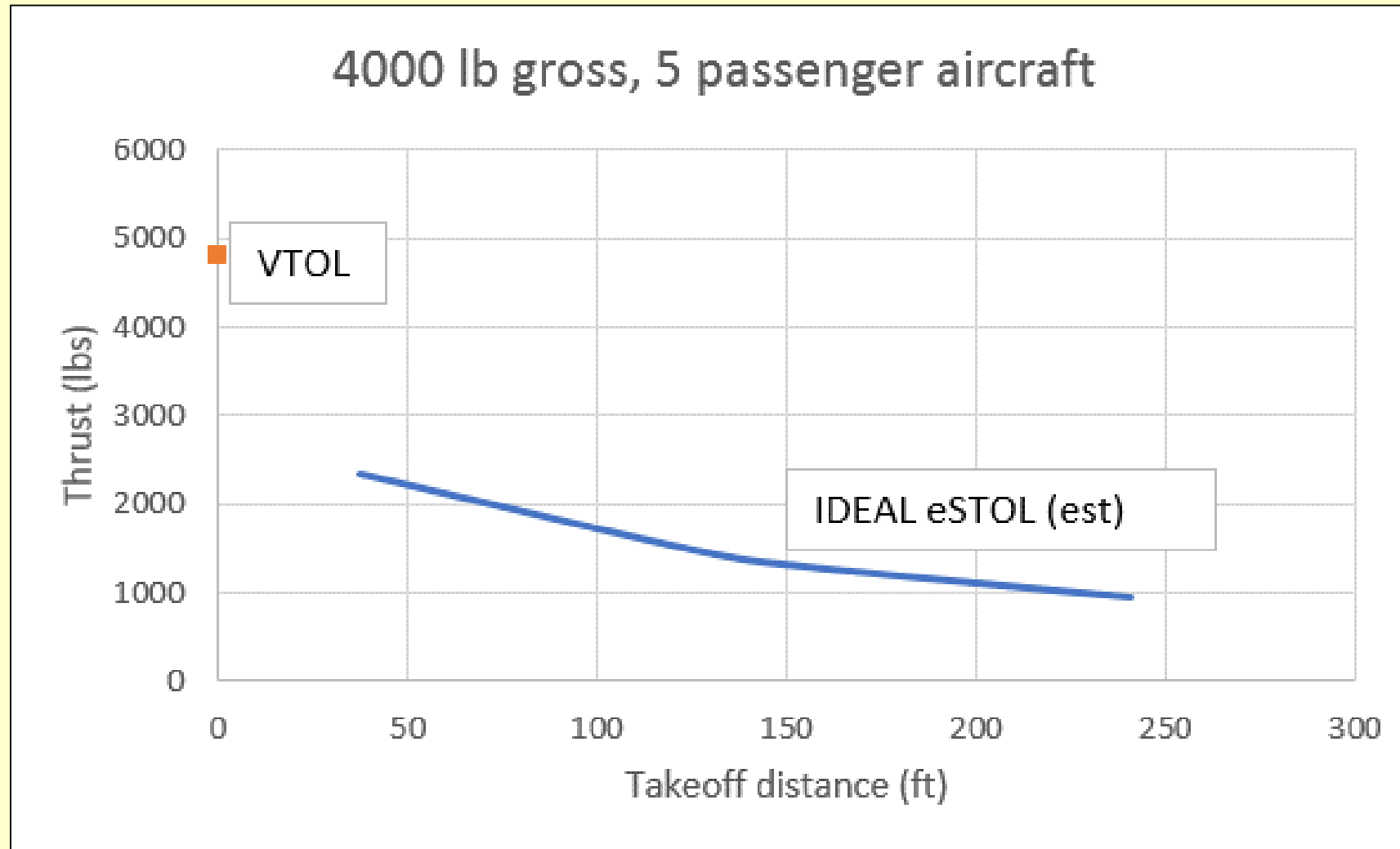






eSTOL is competitive with eVTOL





Takeaway: eSTOL can be designed to give very short take-off distances!

Takeaway: VTOLs need 2-5 times the power of eSTOL to take-off!

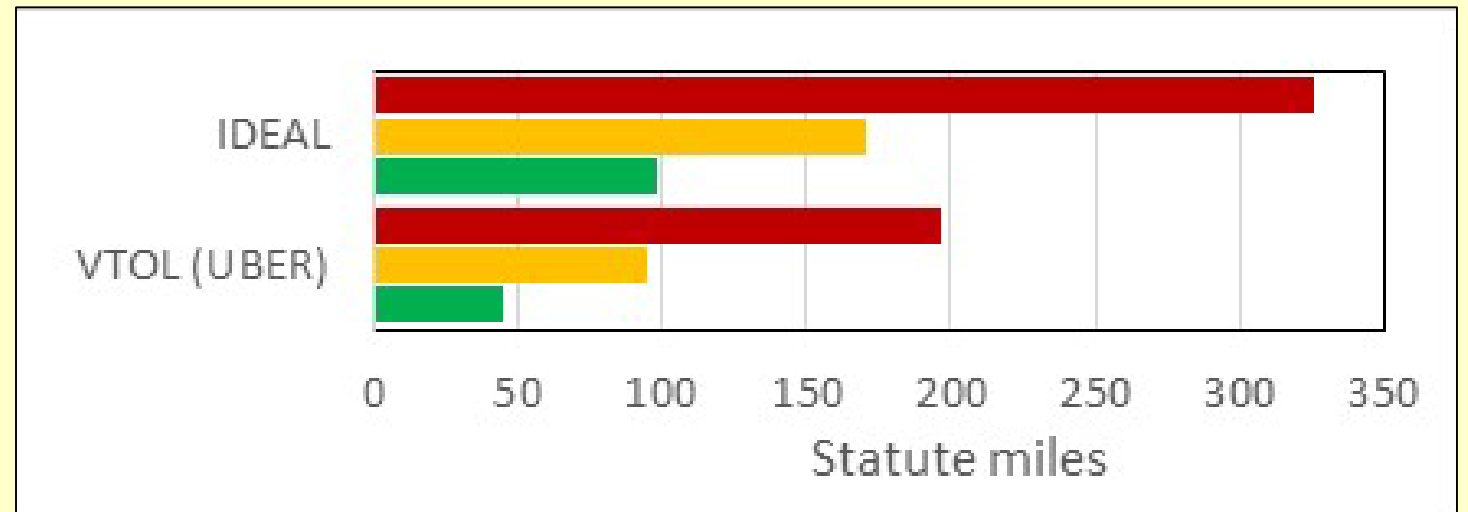
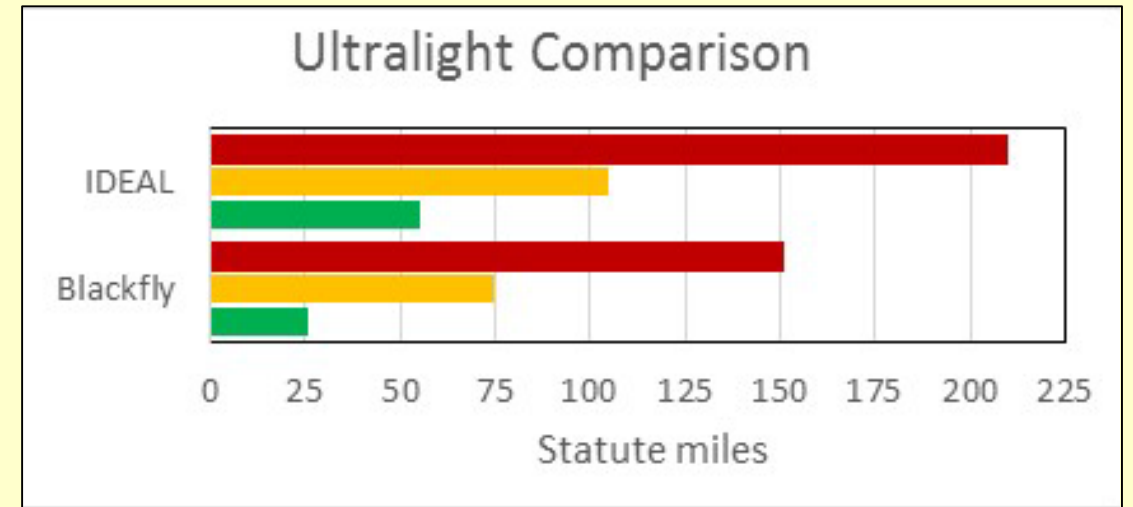
Specific Energy and Range

Specific Energy

2040 batteries (400 wh/kg)

2023 batteries (230 wh/kg)

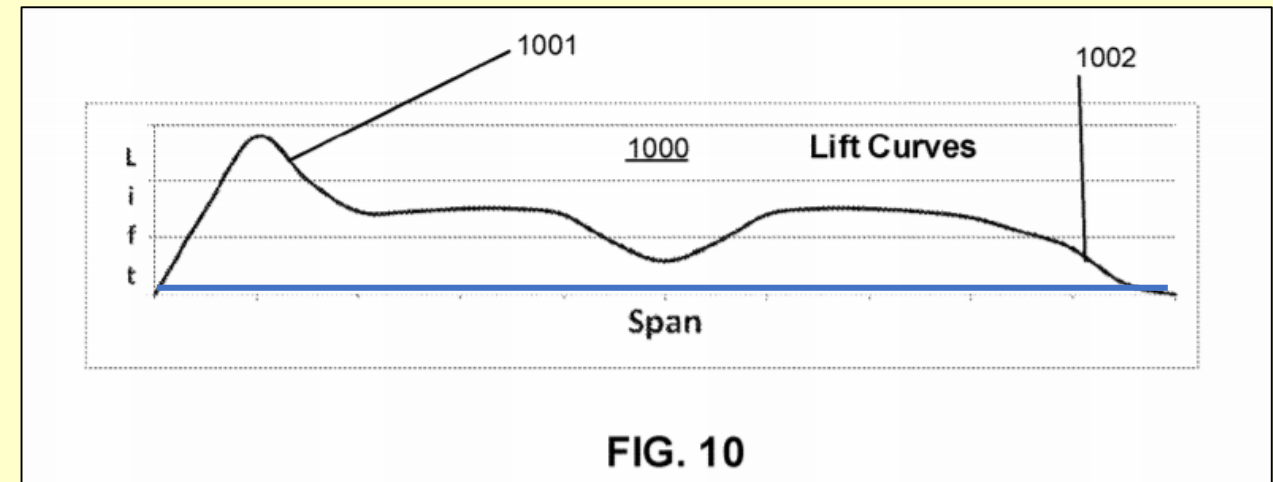
Current batteries (150 wh/kg)



Takeaway: eSTOL has nearly twice the range of eVTOL regardless of battery maturity

IDEAL can Reduce Loss Of Control (LOC) incidents

1. Increasing the lift curve slope giving higher lift at lower airspeeds;
2. Reducing the potential for separation increasing the maximum lift and delaying stall;
3. Increasing flap effectiveness resulting in higher lift at even lower airspeeds; and
4. Managing the spanwise lift distribution improving control at low airspeeds.



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- Propulsion-Airframe Interaction (PAI) may be key to eSTOL and, it too, is understudied.
- IDEAL is an on-going, self funded project to explore PAI for eSTOL.

Thank you for your attention

Contact info

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