

# **Hybrid electric aircraft concepts, and a rational approach to success**

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What I'm going to cover today-

- Why near-term battery performance dictates that a hybrid electric drivetrain solution is preferred for the next 15 years
- A few "thought experiments" about airplane configurations from 1 to 10 seats using a variety of hybrid solutions
- A suggested approach to rationally communicate the performance of proposed hybrid electric aircraft

**The project that got me interested in hybrids - world's first manned fuel cell hybrid electric airplane, flew in February 2008**

A hybrid configuration with Saft Lithium-ion batteries, UQM motor, and Intelligent Energy fuel cell stacks

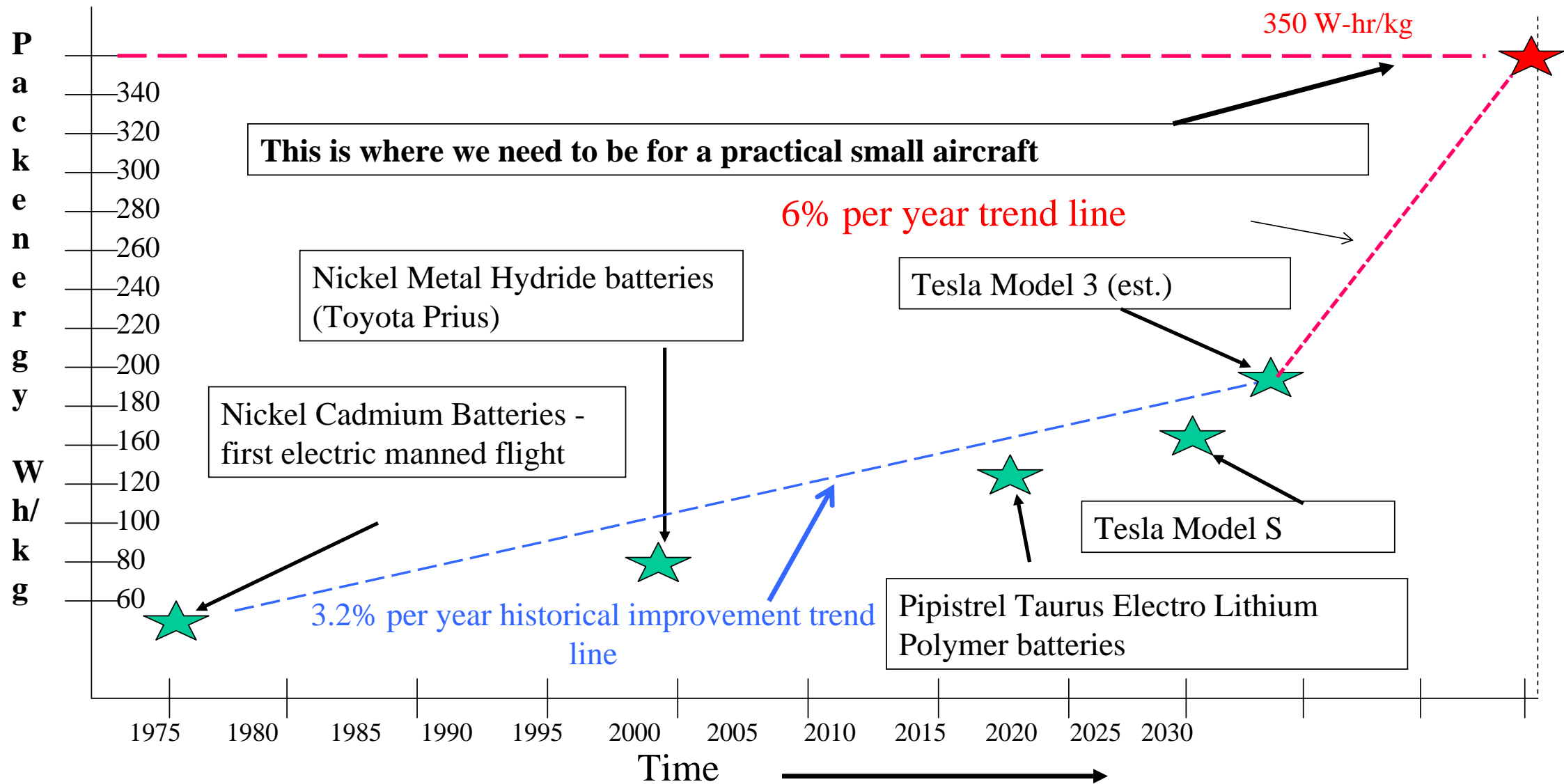


# Battery Packs – why is this so hard?

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- Automotive battery packs have gone past the tipping point for practicality – but they are really heavy. Cars and buses can tolerate a heavy battery pack, airplanes can not!
- For a production aircraft, you need to think about more than just the bare battery cells. You need to consider the weight of the BMS, cell cooling/heating, charging/swapping provisions, and a containment system acceptable to the FAA.
- An engineering analysis of a two seat sporting aircraft showed that in order to match the performance and range of a gasoline motor with a battery powered plane, the **pack** specific energy needs to reach 350 W-hr/kg.
- Industry experts feel that a 6% per year improvement curve is possible, given the current amount of research effort

# A little history of battery pack performance -



## **Conclusion –**

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There is a ~ fifteen year window (2017 – 2032) in which the preferred electric airplane configuration will be a hybrid for all but flight training or short duration flights. Past that date, available battery pack performance will allow pure electric flight with reasonable payload and range.

**What follows are some suggestions for hybrid configurations from 1 seat to 10 passengers.**

# Series or parallel hybrid?

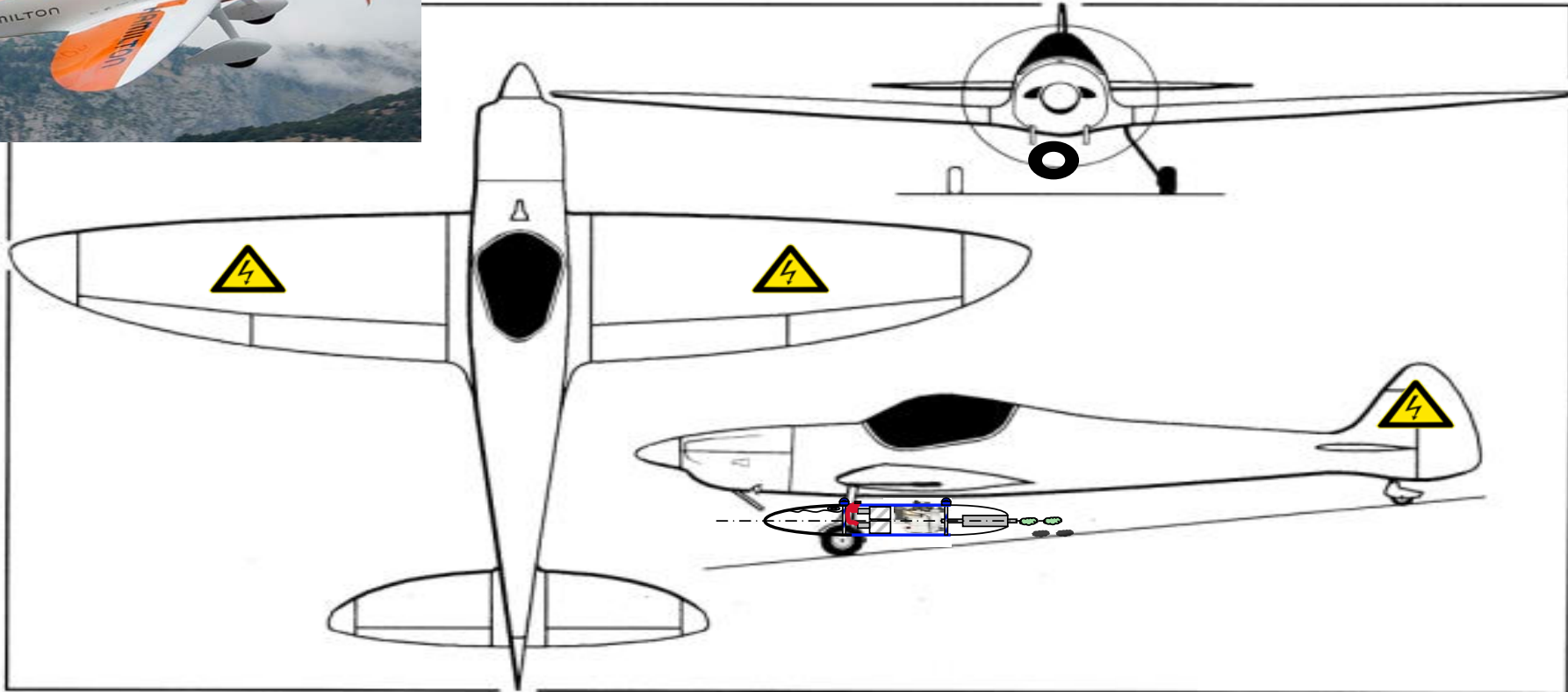
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**Series hybrid** = mechanical power comes only from the electric motor

**Parallel hybrid** = mechanical power comes simultaneously from electric motor and an internal combustion motor

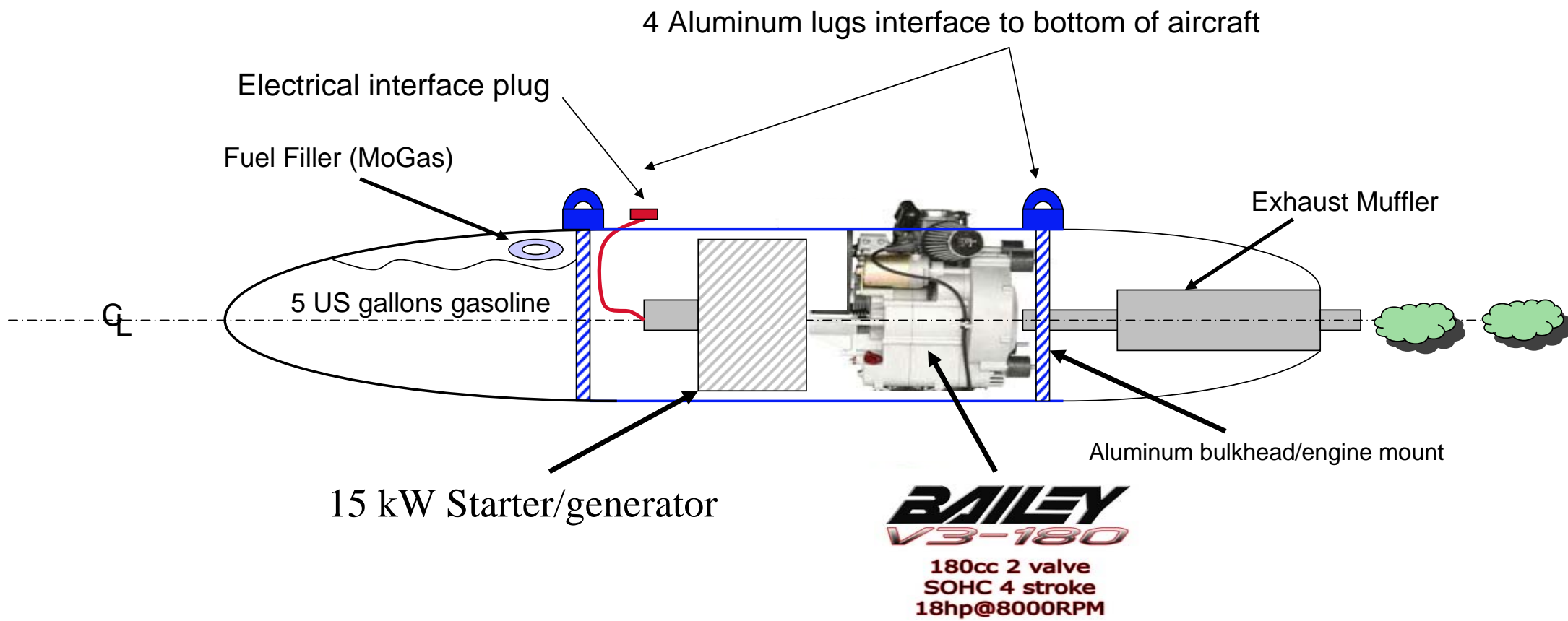
**Series/parallel hybrid** = mechanical power can come from the electric motor and internal combustion engine independently, or in conjunction with each other

# The Electric Twister Range Extender Pod – an example of a series hybrid system

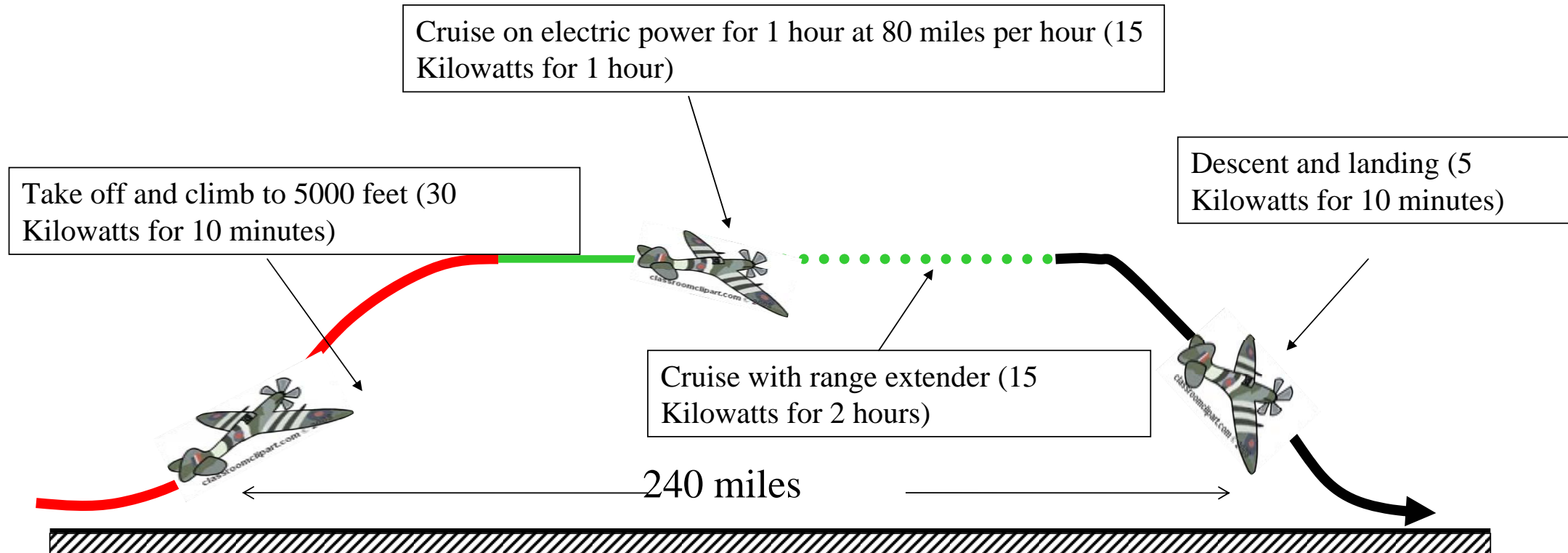




# The Electric Twister Range Extender Pod



# Long range hybrid flight with range extender – very light aircraft at low power settings



**Total Energy Required: ~ 50 Kilowatt-hours**  
(20 from batteries and 30 from range extender pod)

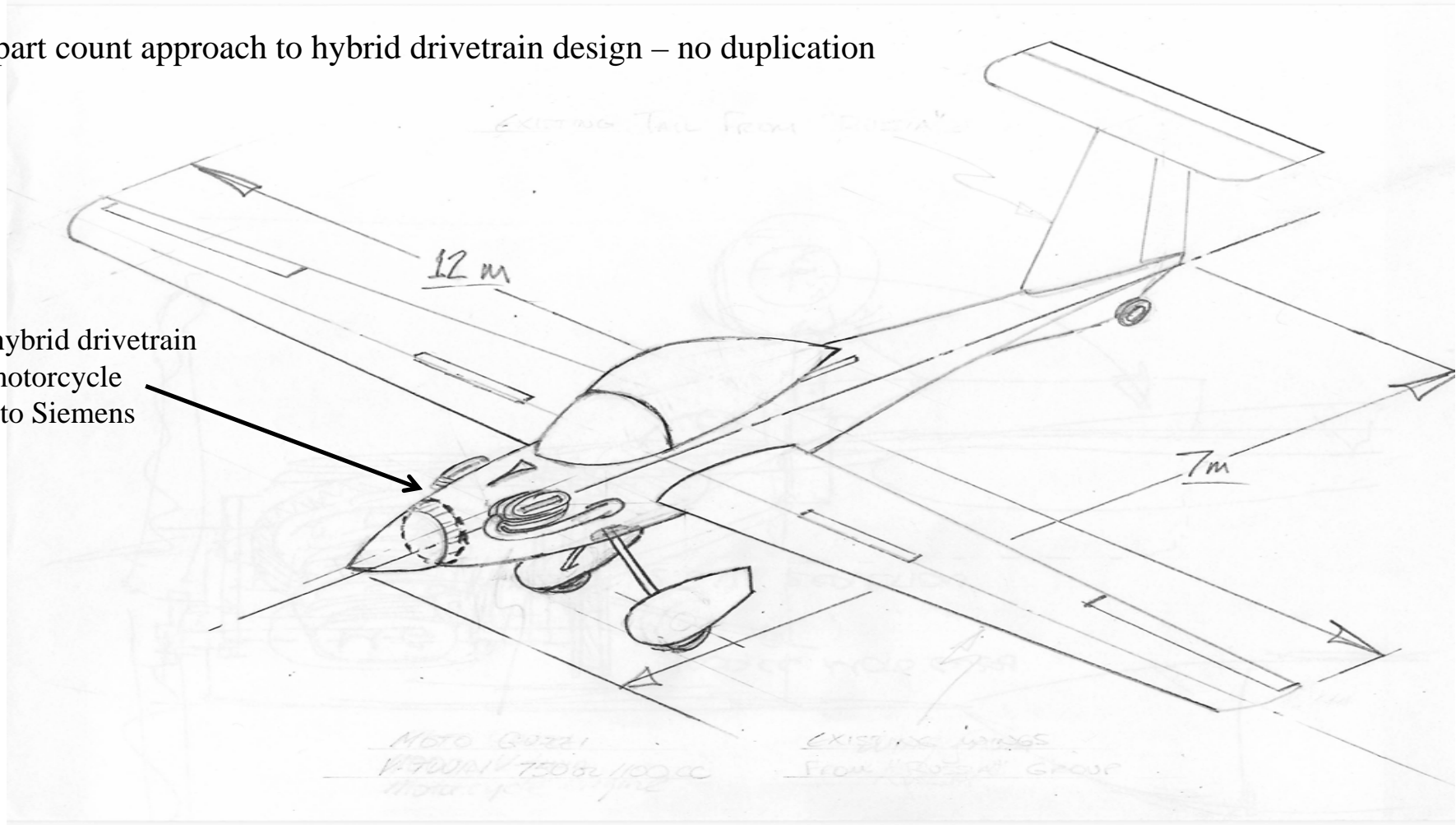
# The MF6 single seat sport motor-glider

## - a series/parallel hybrid configuration

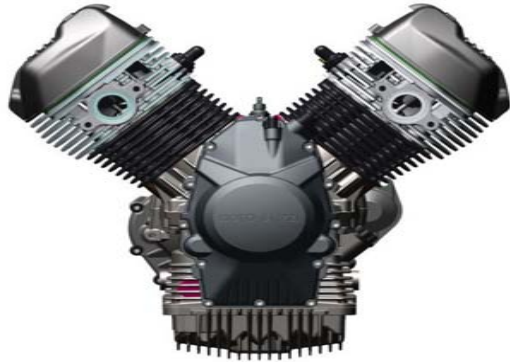


- a minimum part count approach to hybrid drivetrain design – no duplication

Series/parallel hybrid drivetrain  
– Moto Guzzi motorcycle  
engine coupled to Siemens  
electric motor



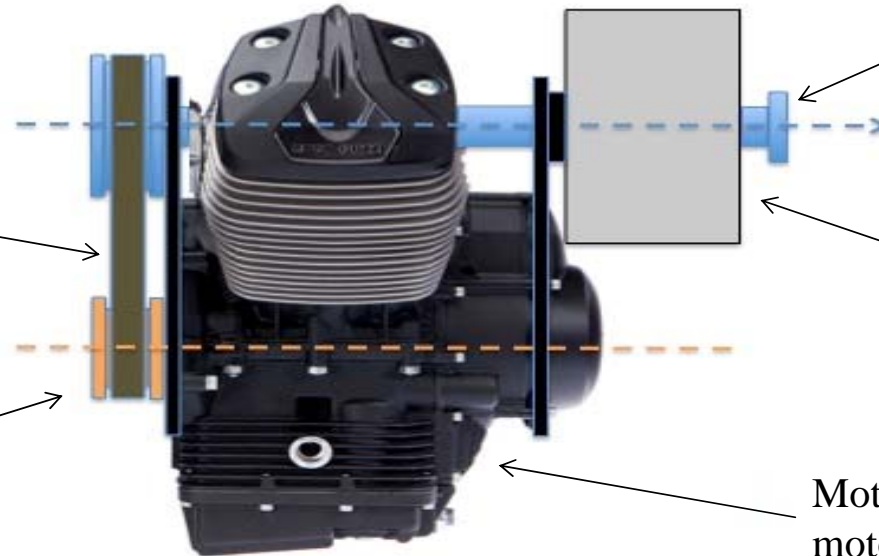
# MF6 series/parallel hybrid drivetrain – Moto Guzzi V9 motorcycle engine coupled to Siemens SP45DH electric motor



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Gates belt provides 2:1 reduction to driven shaft running in-between cylinders



Prop flange

Siemens motor

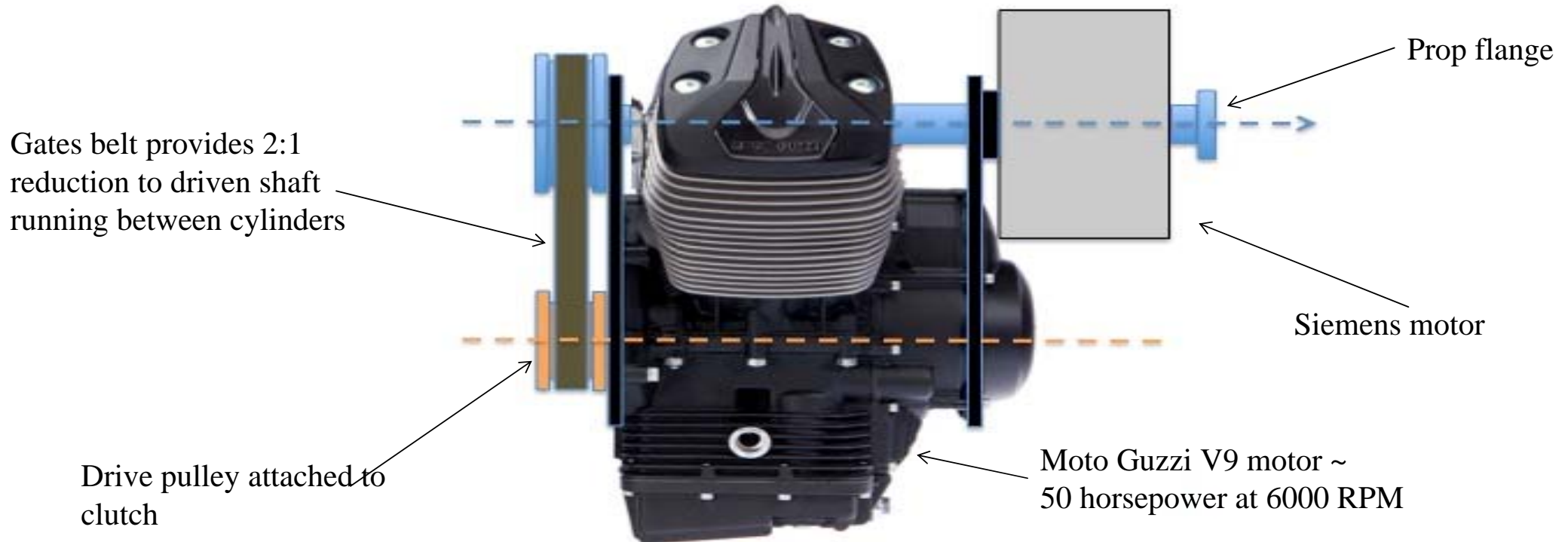
Drive pulley attached to clutch

Moto Guzzi V9 motorcycle engine

## Simplified hybrid drivetrain eliminates duplication

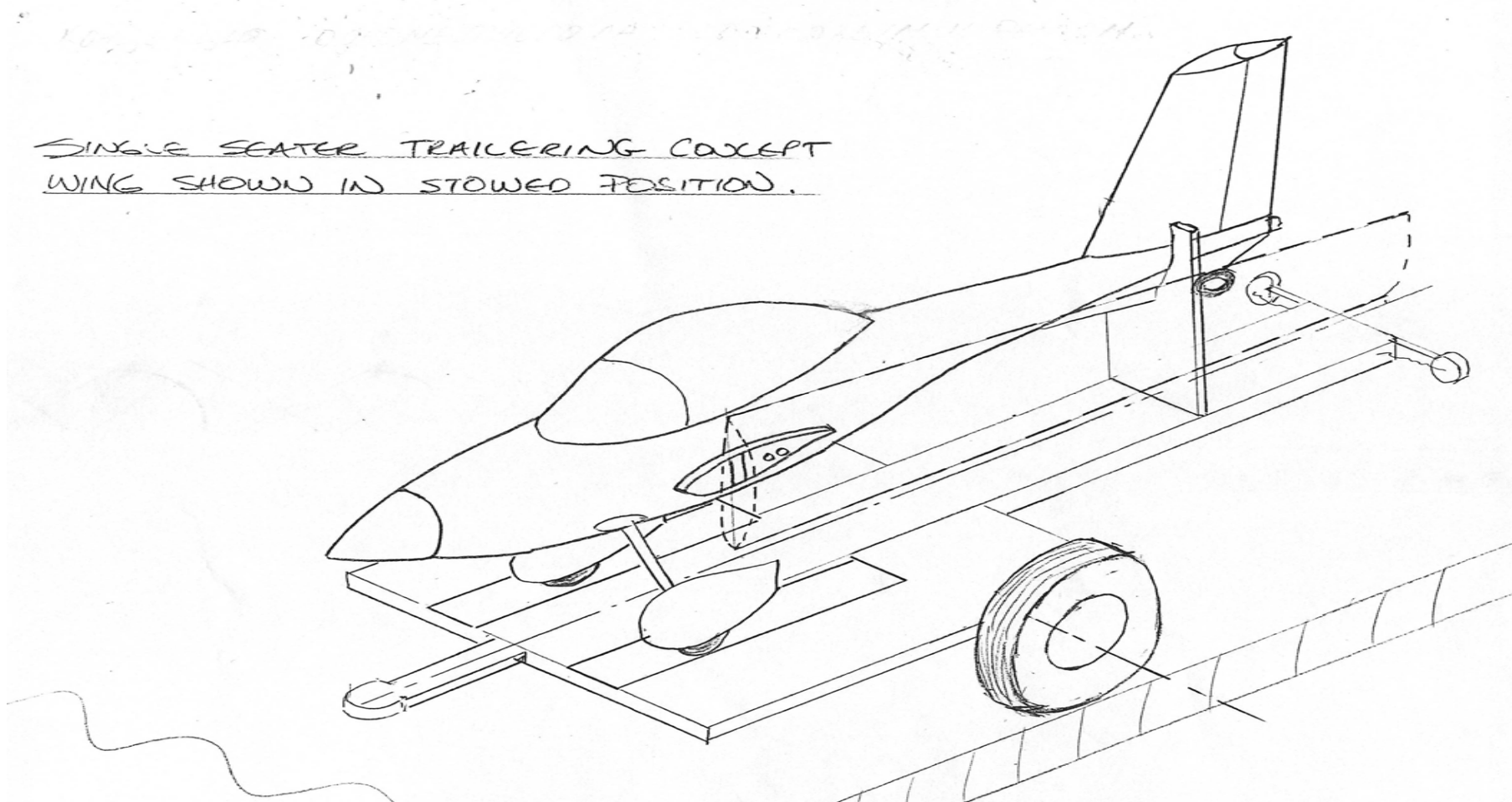


- no duplication of generator/motor – drive motor starts gas engine
- minimizes electrical components – one motor/generator controller
- clutch allows 3 modes – electric only, electric + gas, gas only
- Twin engine safety with a single prop allows use of off-the-shelf engine



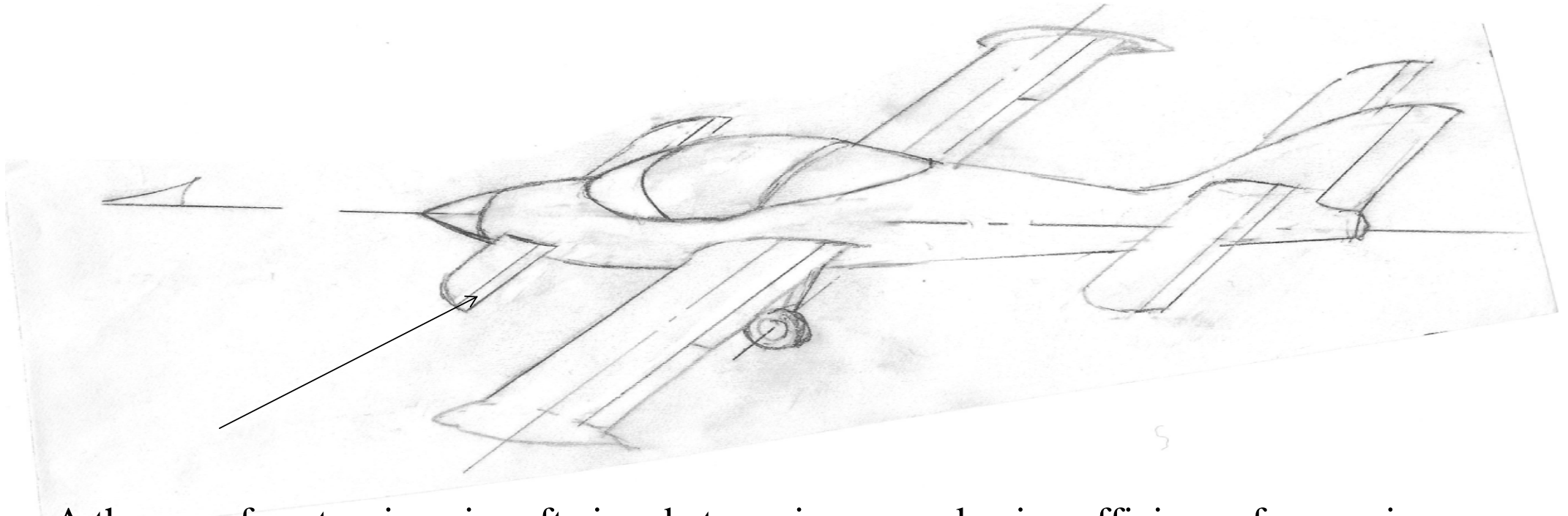
# The MF6 sport motor-glider

- wings remove easily for transportation to home



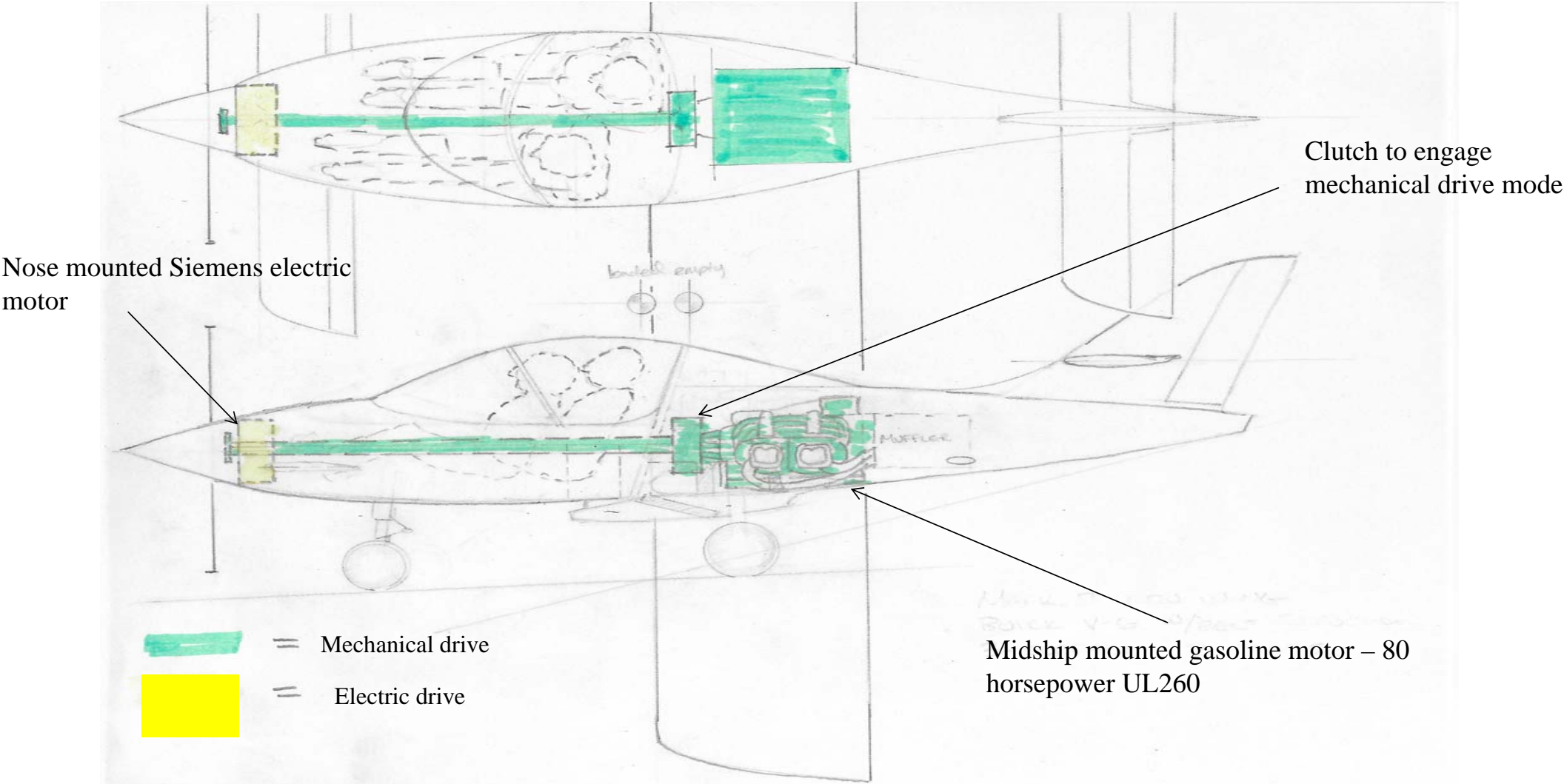


# The MF1 two seat series/parallel hybrid touring aircraft



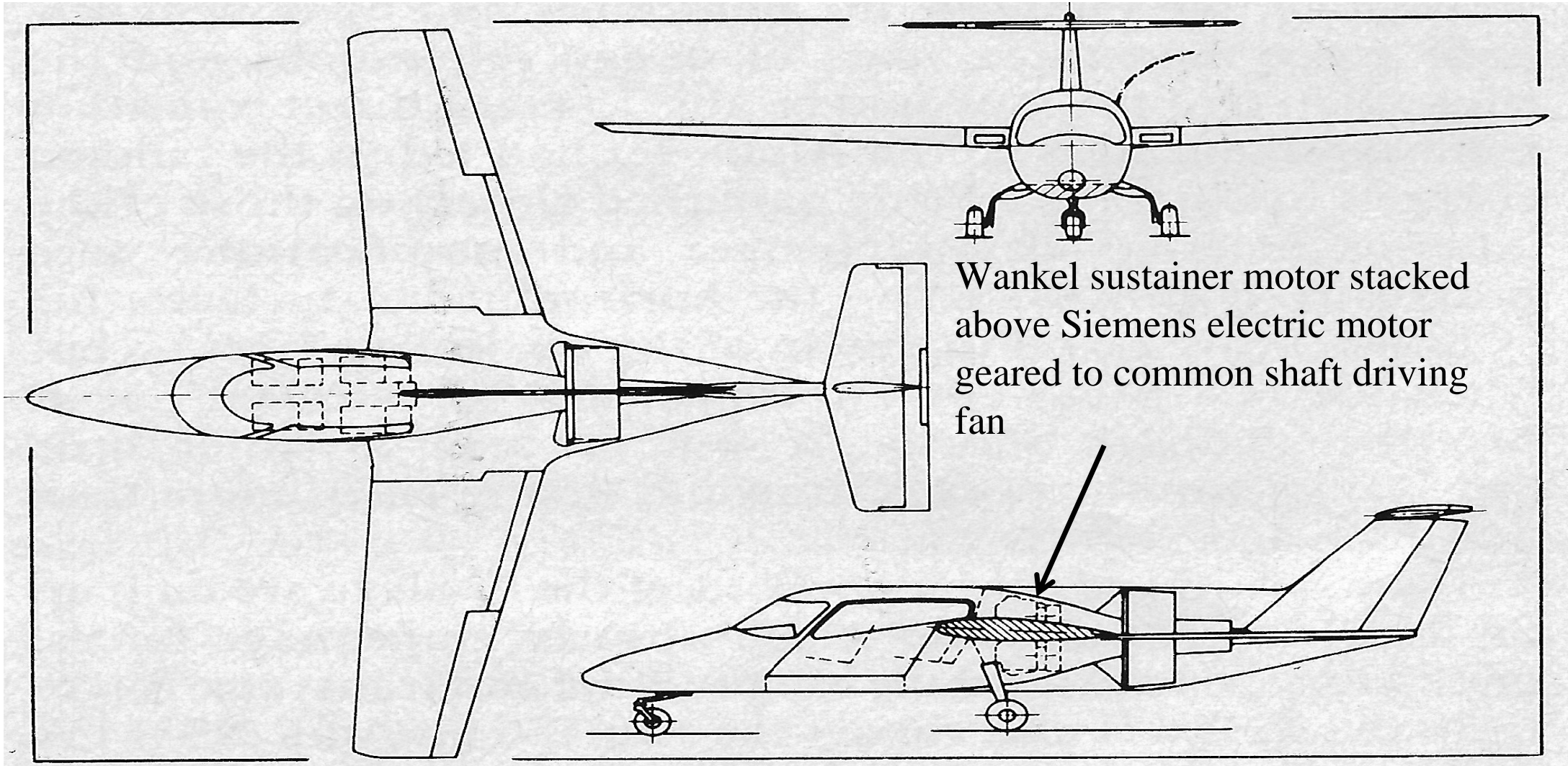
A three-surface touring aircraft aimed at maximum packaging efficiency for a series-hybrid drivetrain.

# The MF1 two seat series/parallel hybrid touring aircraft





# A five seat series/parallel hybrid ducted fan touring aircraft



# The Zunum ten seat commuter aircraft

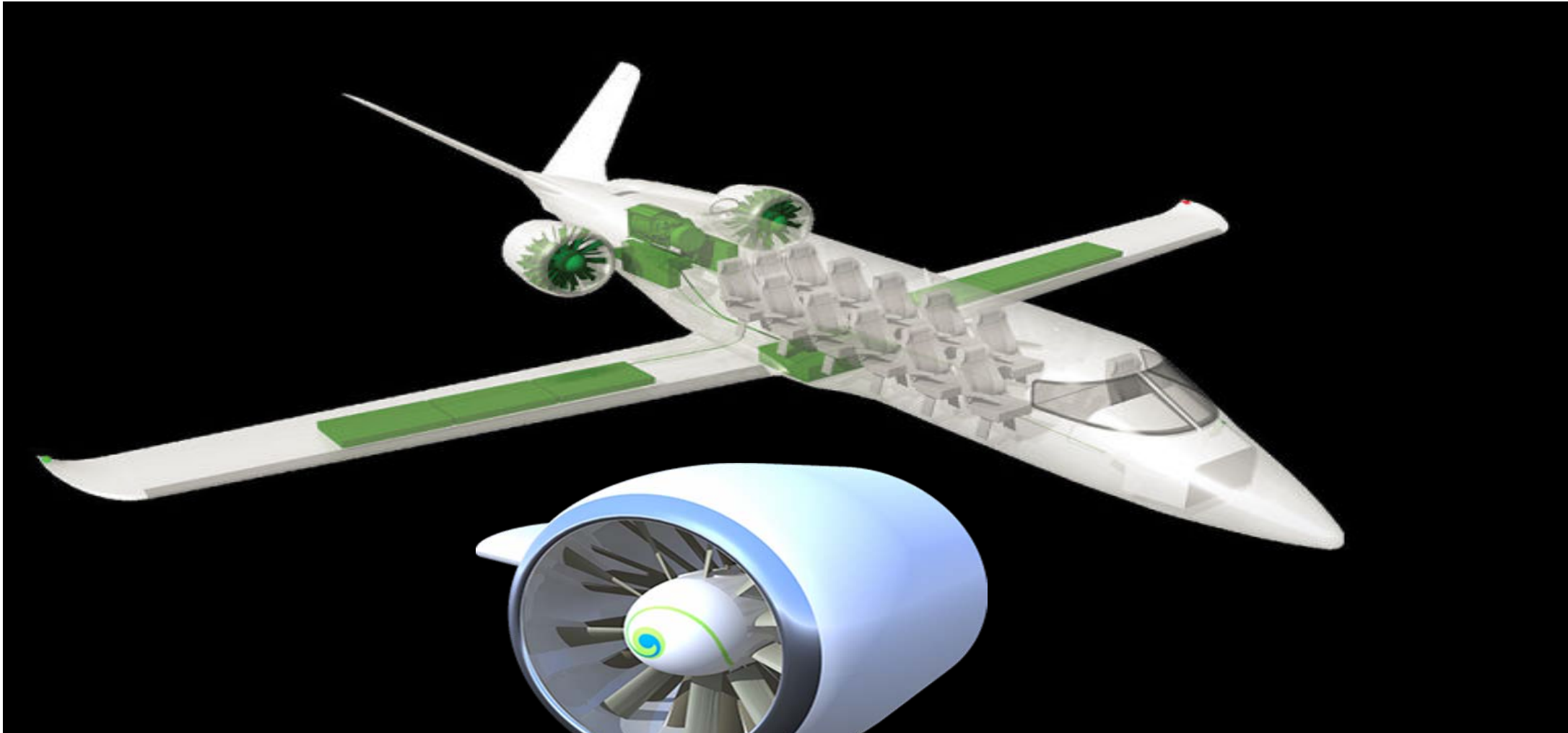
Hybrid drivetrain  
provides operating  
costs far below current  
10 seat commuter  
aircraft







## The Zunum ten seat commuter aircraft – drivetrain layout

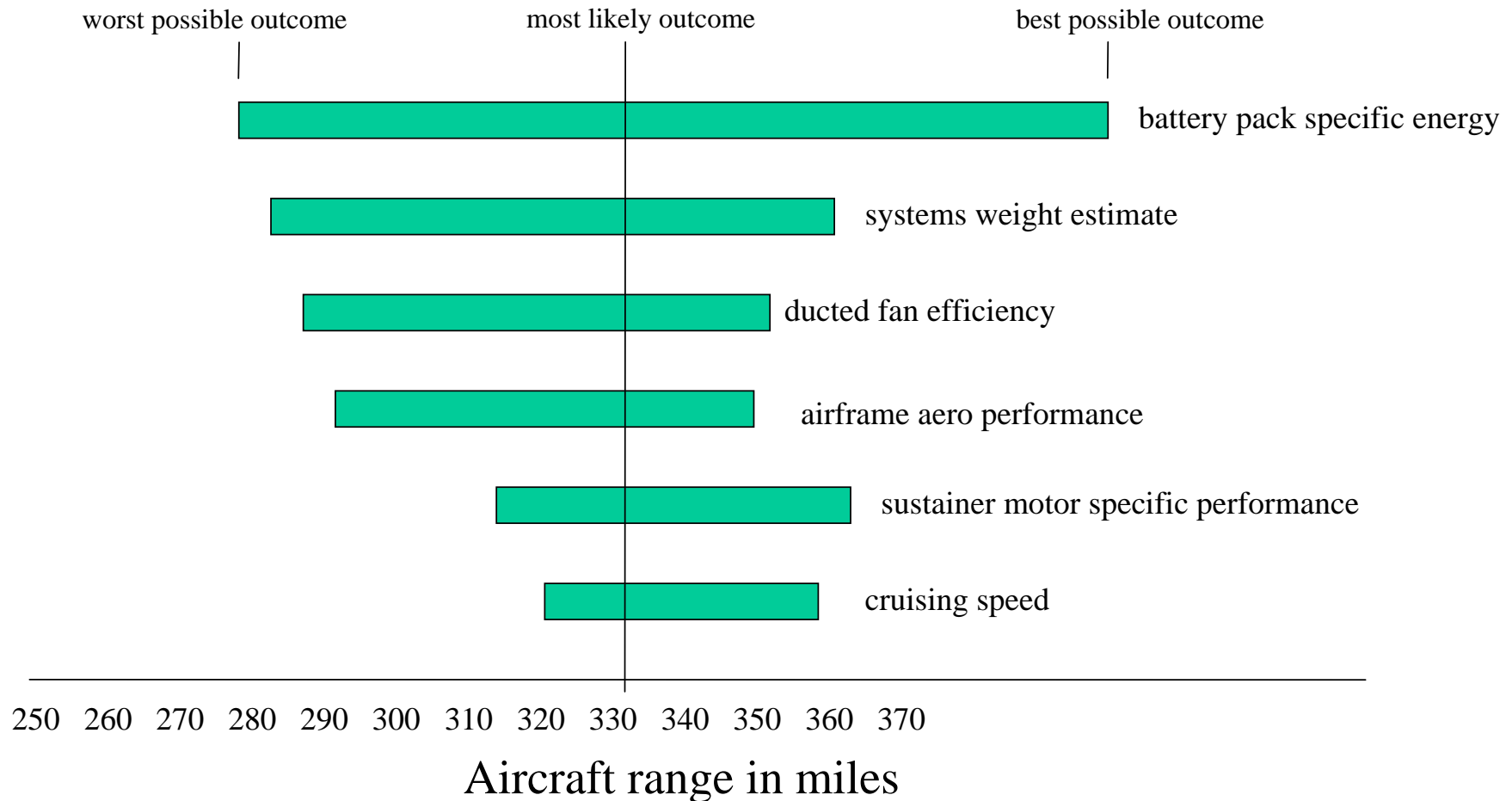


# Electric aircraft performance – how to predict?

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- All too often, performance projections for electric aircraft are based on extremely optimistic assumptions of battery performance, systems weight, and aero performance.
- These optimistic assumption can lead to designing the wrong airplane – wing area, power required, range, and cost.
- At the early design stage, it is much easier to predict "how good could it be, how bad could it be, and what is the most likely outcome?" for a range of factors effecting airplane performance.
- Use of a "tornado diagram" can give a much more honest assessment of most likely outcome to investors and designers, and focus work on the areas of highest uncertainty.

# A suggestion – use of a "tornado diagram" could better illustrate risks in electric aircraft development



# Conclusions

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- Battery technology available to the public at an affordable price will not allow an all-electric aircraft the range required for practical cross-country flight in the next ten years. A good hybrid design architecture would be one that allows easy conversion from hybrid to all-electric as battery performance improves.
- The use of a parallel hybrid propulsion system can allow cross country flying while retaining the wonderful benefits of a pure electric propulsion system for short flights.
- The use of a series-parallel hybrid propulsion system allows for a lighter minimum part-count solution – preferred for a longer range sports aircraft configuration.
- A series hybrid system using a turbine or (later) diesel sustainer motor makes for a low operating cost 5 to 10 seat commuter aircraft.
- The use of a tornado diagram to illustrate airplane performance risks more clearly communicates probable outcomes and areas to concentrate on.
- **In the near future, an airplane configuration built specifically around hybrid electric propulsion will be measurably better than today's internal combustion based configurations.**