Going from IC → Electric

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RAeS LAG Conference

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Two things…

Your speaker

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CEng

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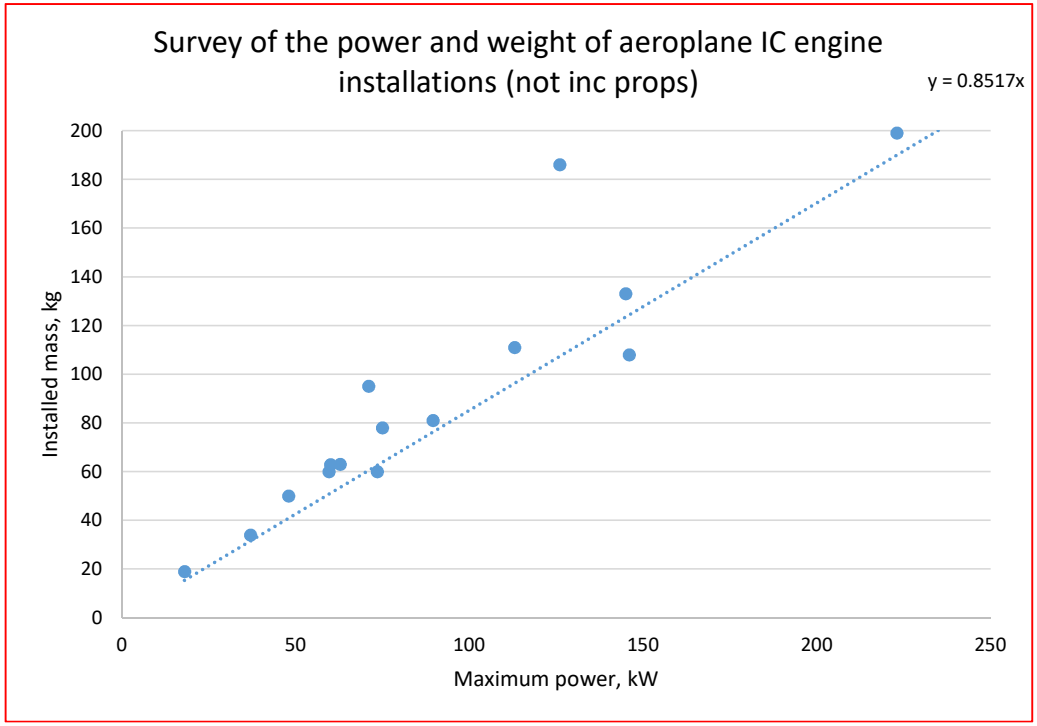
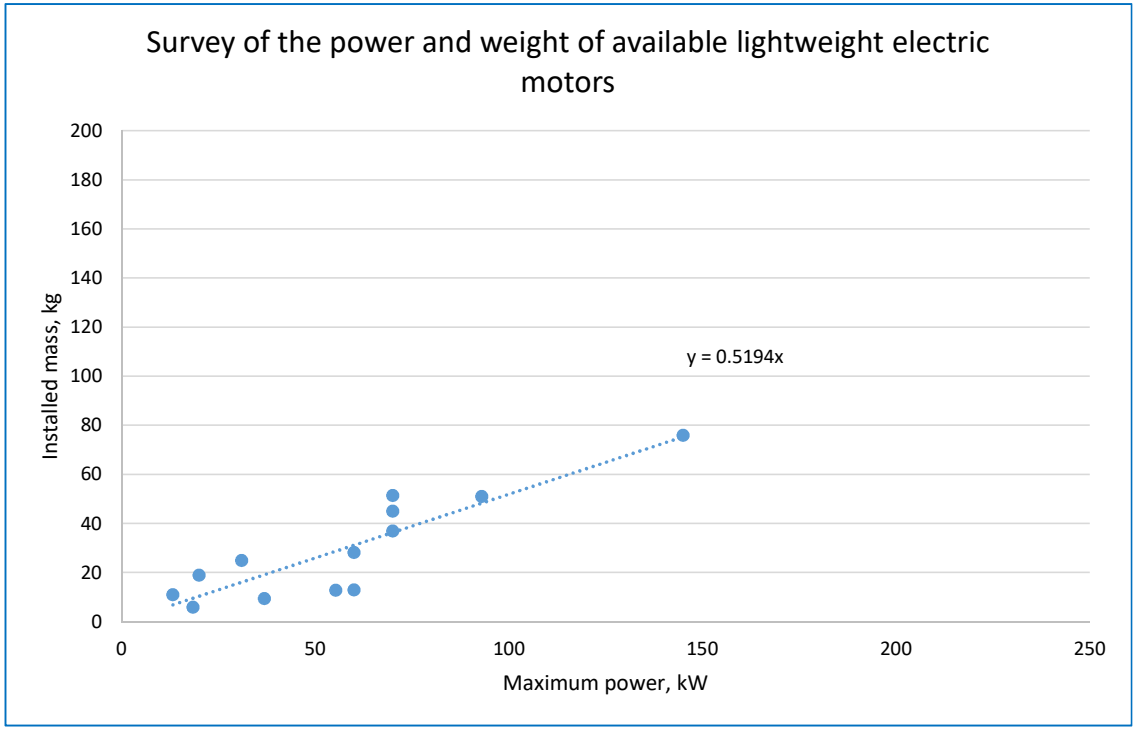
Health Warning

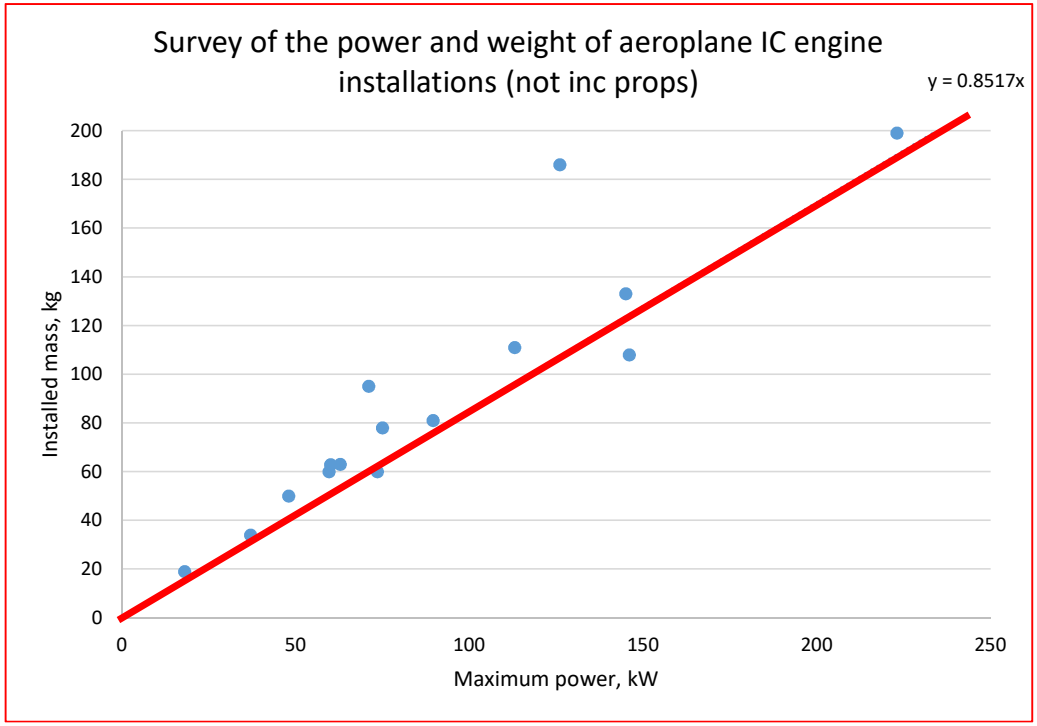
This presentation will contain lots of maths.

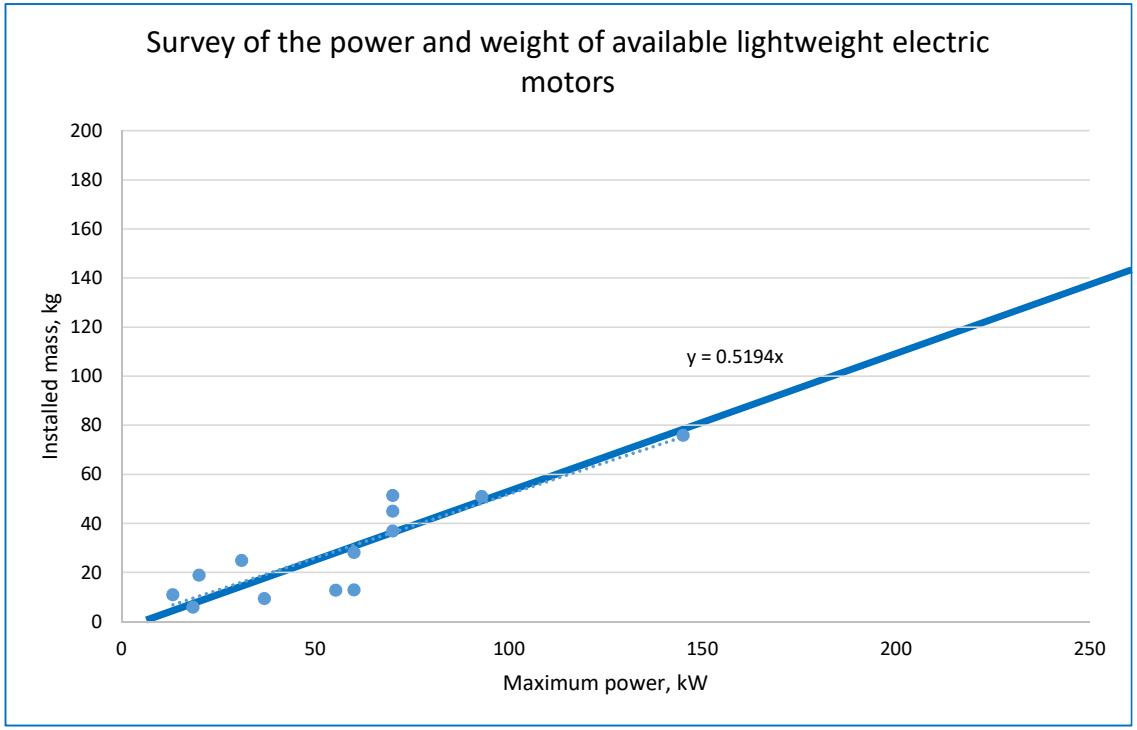
Engines versus motors: mass versus power





Engines versus motors: mass versus power





0.85 kg/kW

→

$^{1}/_{3}^{rd}$ less

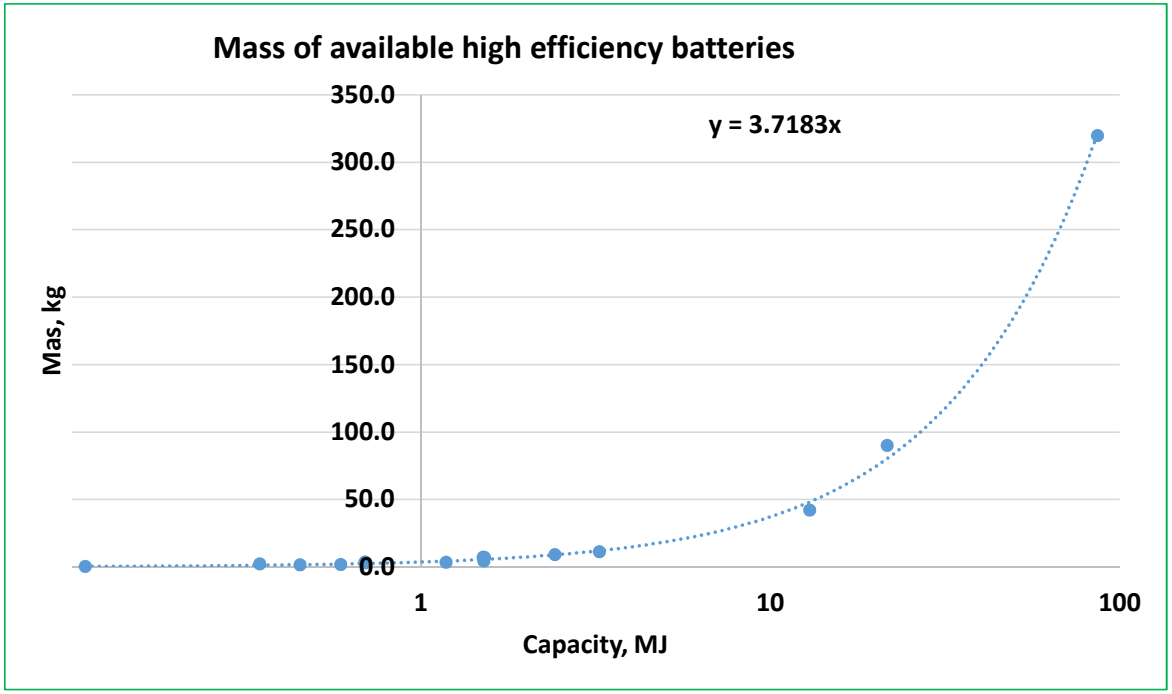
0.53 kg/kW

Fuel versus batteries mass

AVGAS: 46 MJ/kg

AVTUR: 42.5 MJ/kg

Li-Ion batteries: 3.7 MJ/kg



x 11½ → 12½

System efficiency

Internal Combustion

- Engine efficiency ~ 20%
- Prop efficiency ~85%

0.2 x 0.85 = 0.17

Total efficiency ~ 17%

All electric

- Battery charge efficiency ~85%
- Brushless motor efficiency ~90%
- Prop efficiency ~85%

0.85 x 0.9 x 0.85 = 0.65

Total efficiency ~65%

x 3.8

So…

- Electric motor is (~1/3rd) lighter than an engine 
- Batteries are (11½ - 12½ times) heavier than fuel 
- Electrical systems are (3-4 times) more efficient than petrol systems. 

What can we do then? – ≤300kg SSDR

- For a range of aeroplanes
  - Take typical empty aeroplane: subtract weight of engine
  - Add mass of motor with same peak power
  - Allow 86kg seat
    - If 1hr at max power is possible, it's viable

Viable?

Yes

- Shadow DD SSDR (1hr)
- Thruster T600T SSDR (1.1hrs)
- Shadow CD SSDR (1.2hrs)
- Thruster TST SSDR (1.3hrs)
- Chevvron 2-32c SSDR (1.8hrs)
- MW5 (1.8hrs)
- Minimax (2.0hrs)

No

- AX2000 SSDR
- Thruster T600N SSDR
- AX3 SSDR
- X'Air SSDR
- Aviasud Mistral SSDR
- Easy Raider SSDR

What's the electric SSDR look like (& cost!)

AMF Chevvron 2-32c "SE"

1.8hrs minimum endurance

86kg pilot

Batteries: £27k

Motor: £2k + £1k controller

Whittaker MW5 "E"

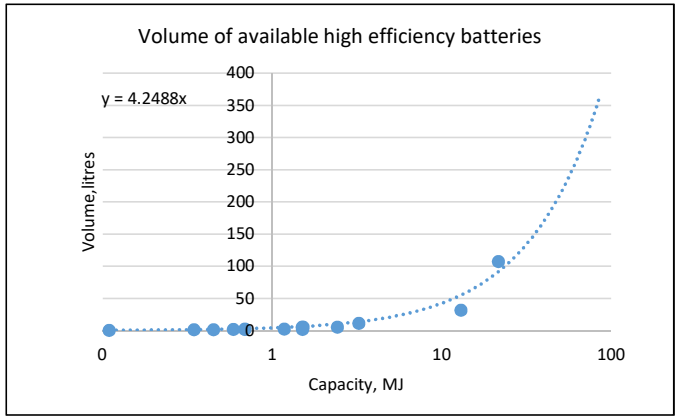
1.8hrs minimum endurance

86kg pilot

Batteries: £46k

Motor: £3k +£1.5k controller

Battery volume and location #1



Fuel: 34-37 MJ/litre

Li-Ion batteries: 4.3 MJ/litre

With 3.8 x efficiency, we need 26% of the onboard energy

$$\frac{34}{4.3} \times 0.26 = 2.06$$

So we need ~2.1 x the volume for energy storage

(But remember – fuel fills complex shapes, batteries won't.)

Battery volume and location #2

All SSDR store fuel in fuselage

Usually spare space. BUT…

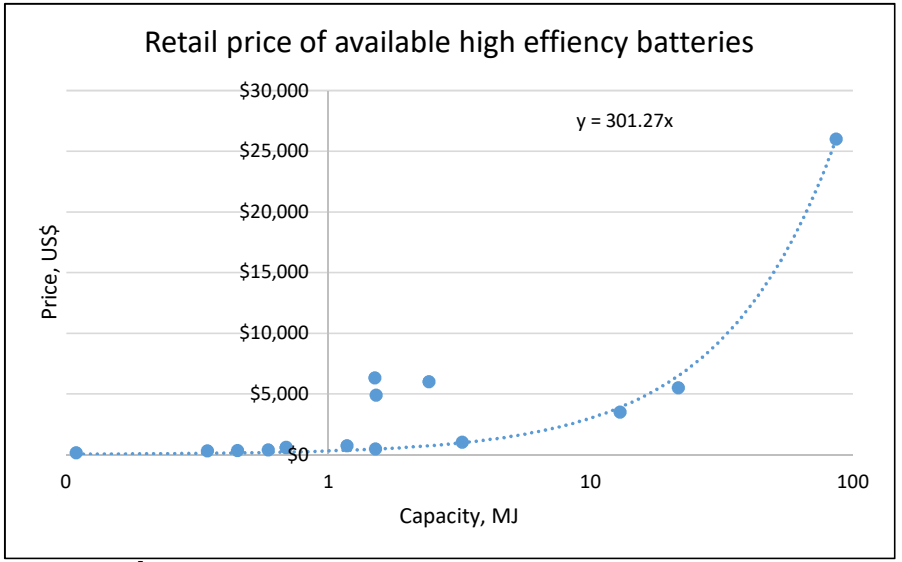
30 litres / 22kg + tank & structure, becomes…

(MW5) 62+ litres / 54kg, batteries, or

(Chevvron)37+ litres / 42kg.

+ structure

In summary – electric SSDR



(1) It's possible

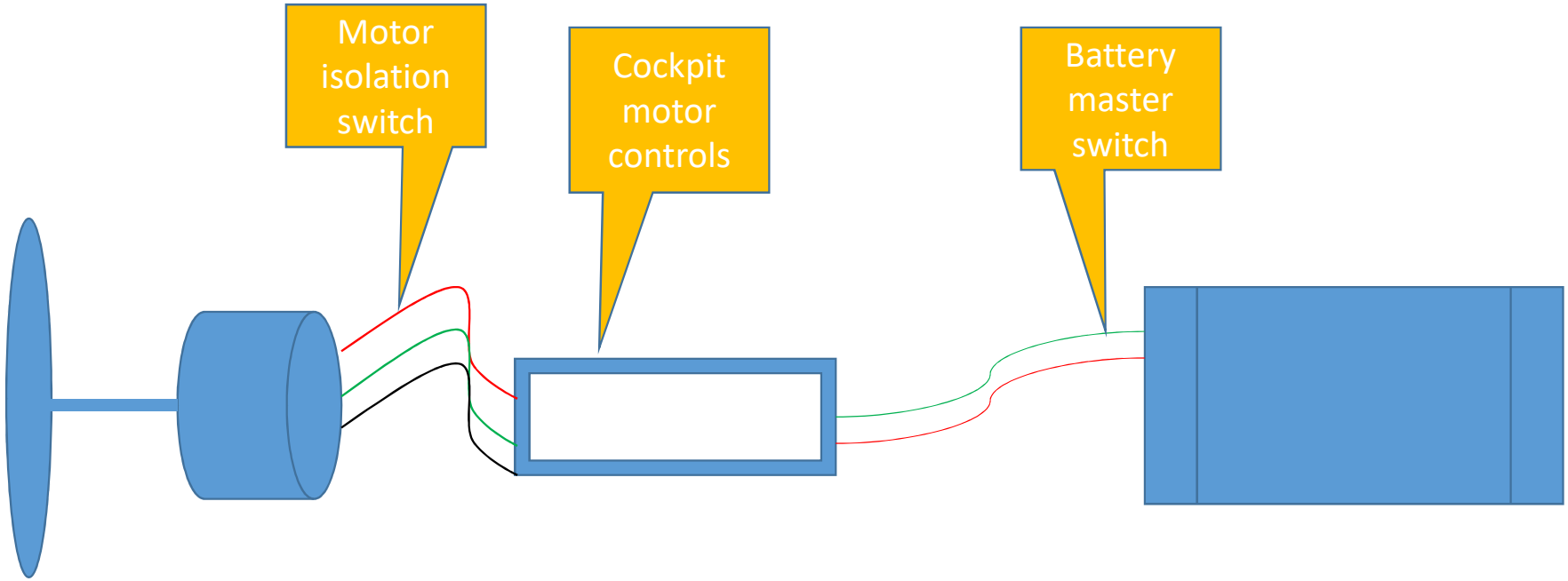
- Similar performance to piston engine
- 1-2½ hrs endurance

(2) Favours light low power (requirement) aeroplanes

(3) Will cost airframe + £30-£50k, plus engineering work

- Will need to increase energy storage volume

Electric SSDR powertrain arrangement



Prop [Fixed]

Motor [AC]

Motor control unit

DC Wiring

Batteries [Li-Ion]

First step up – SSDR to 2-seat microlight

Upgrade aspects

- Duplicate batteries *(Pipistrel Alpha Electro already has)*
- Crashworthiness enhancements around batteries



Viable and non-viable types

- Viability criterion: 86kgx2, 1hr MCP, similar performance

Yes

- Aviasud Mistral (1.1hrs)
- Thruster TST (1.1hrs)
- Bantam (1.2hrs)
- Thruster T600T (1.2hrs)
- X'Air Mk.1 (1.5hrs)
- Easy Raider (2.6 / 1.9hrs)
- Chevvron 2-32c (2.0hrs)

No

- Breezer
- Eurofox
- Sherwood Scout
- CT
- Eurostar
- SLA
- C42
- Thruster T600N
- Cyclone AX3 / AX2000
- Sky Ranger
- X'Air Mk.2
- Savannah
- Escapade
- Jabiru Calypso
- MXP740 Savannah

What's the electric 2-seat microlight look like (& cost!)

Chevvron 2-32c "2E"

2.0hrs minimum endurance

172kg pilots

Batteries: £31k

Motor: £2k + £1k

Easy Raider "2E"

2.6 – 1.9 hrs minimum endurance

172kg pilots

Batteries: £80-£92k

Motor: £3½ - £5½ k + ~£2k

So we can have a 2-seat electric microlight too

Cost airframe + £35-£100k + modification work

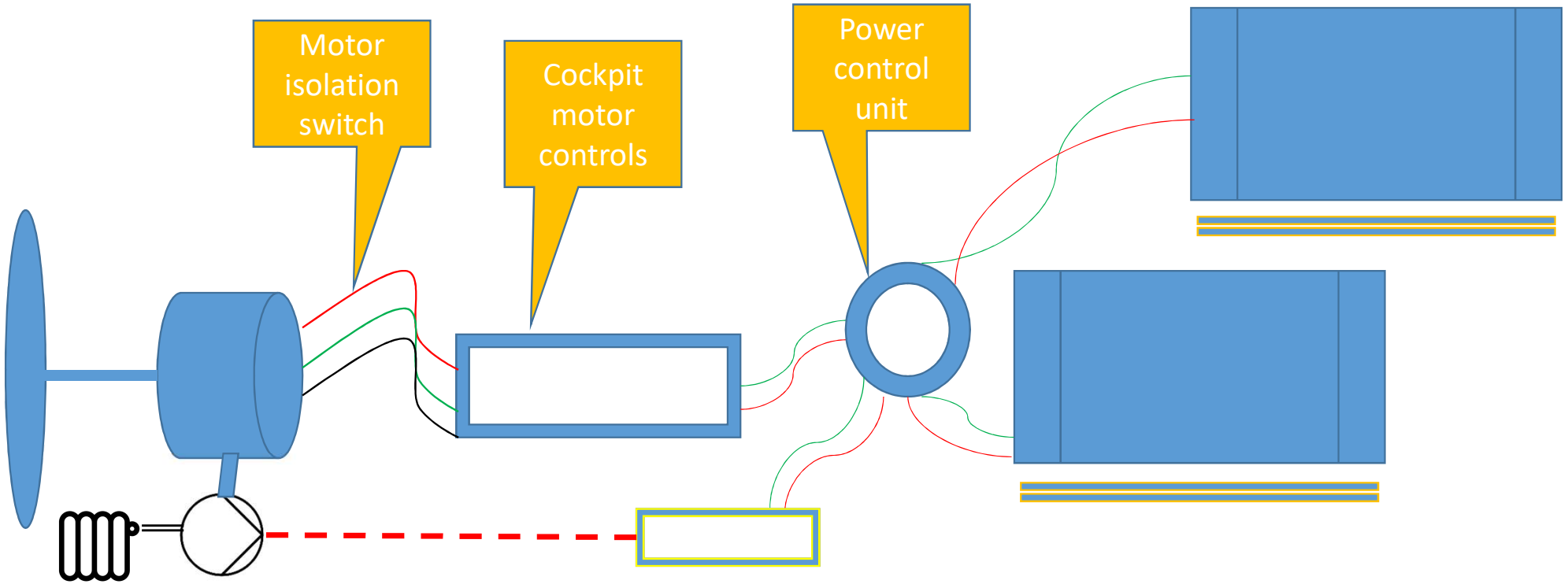
2-4hrs endurance possible

- IF we select lightweight, low power requirement types

(My opinion)

- At this point add
  - Battery crashworthiness and fire protection
  - Duplicated battery arrays
  - More complex power control unit

Electric 2-seat microlight powertrain arrangement



Prop [Fixed]

Motor [AC]

Motor control unit

DC Wiring

Batteries (2 arrays) [Li-Ion]

Crashproofing & fireproofing

Radiator

Coolant Pump

Additional services distribution

How about 2-seat SEP or SLMG?

Type	Endurance @MCP with 2x86kg (hrs)	Price of the batteries	Battery price per hour endurance	Additional Payload with 1 hrs battery capacity & 2POB (kg)	Endurance with 3POB (hrs)
Sky Ranger LS	1.1	£56,000	£49,000	179.8	
Condor	1.1	£69,000	£62,000	180.3	
G109b	1.3	£78,000	£59,000	194.5	
Auster	1.4	£123,000	£89,000	211.7	
Vigilant T1	2.2	£128,000	£59,000	252.5	
Europa XS	2.2	£107,000	£49,000	238.8	
C172R	1.8	£203,000	£111,000	279.0	1.0
Cherokee 140	2.9	£268,000	£94,000	375.8	1.7
Jabiru J430	**3.4**	**£249,000**	**£74,000**	**376.0**	**2.7 (2.0 4POB)**

So, most SEP *could* become “CEP”

Heavier legacy types (PA28, C172, Auster) very expensive: £89-£110k/hr

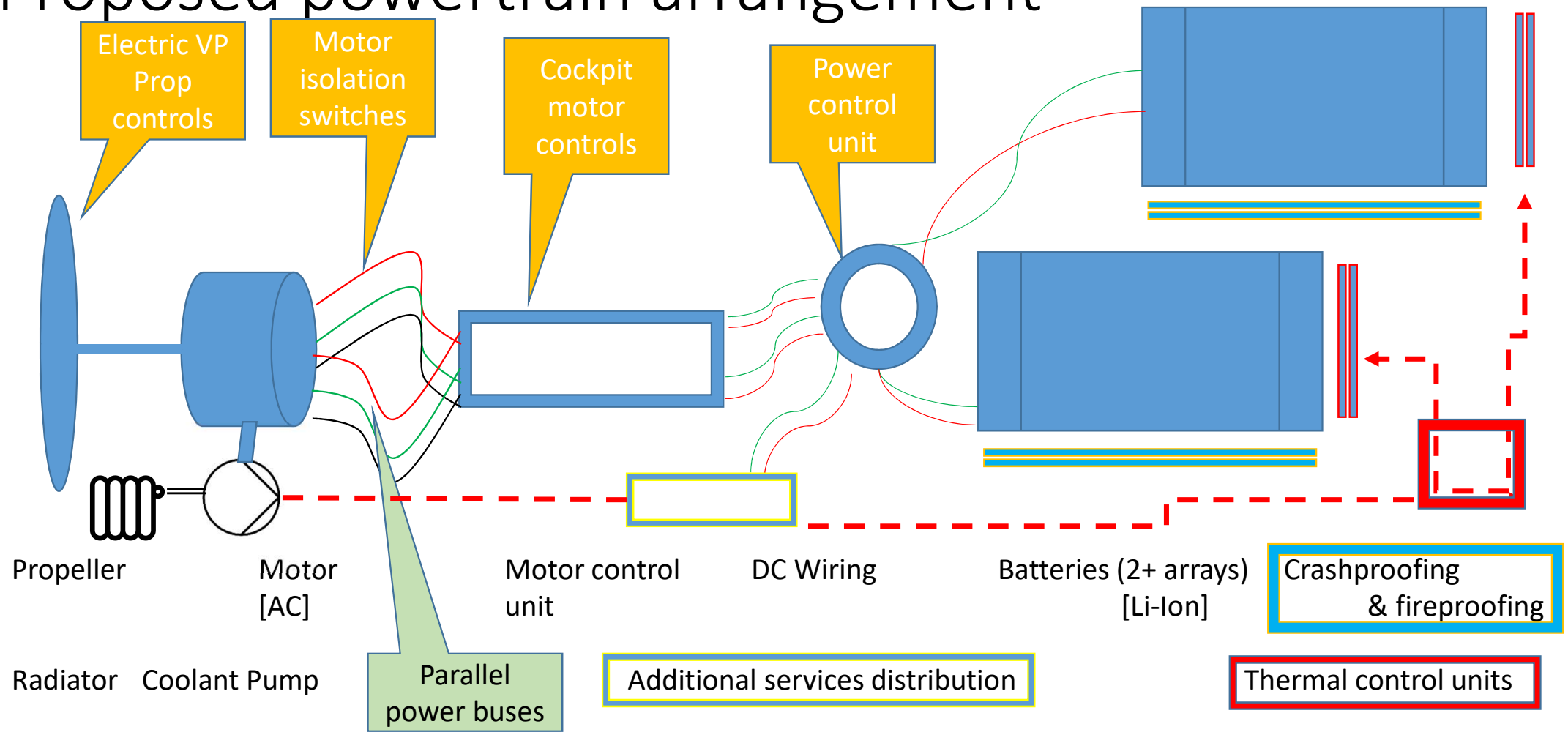
Costs favour lightweight structures (SKR, Condor, Europa): £49-£63k/hr

Like the Chevvron, Motorgliders look good (G109b / Vigilant)

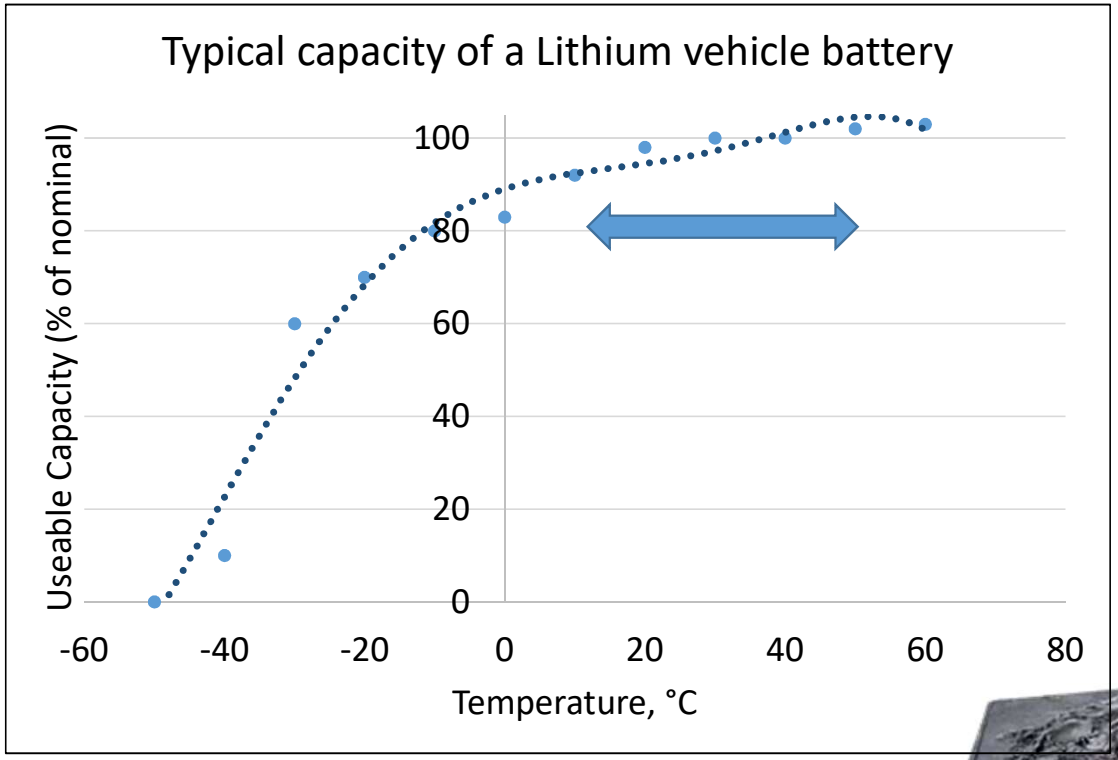
4 seat occupancy is possible (J430) … at a price.

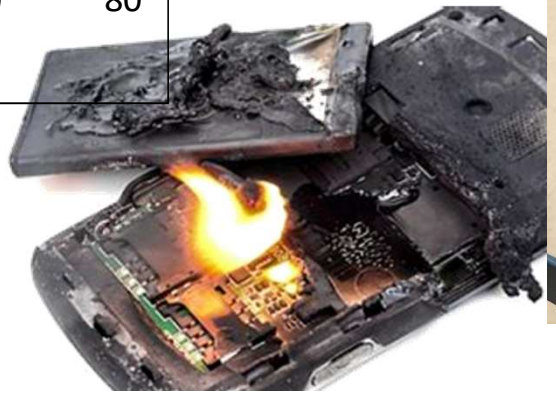
- 2+hrs & 4 adults / 2.7+hrs & 3 adults / 3.4+hrs and 2 adults.
- £74k per hour’s battery capacity

Centreline Electric Propulsion (CEP): Proposed powertrain arrangement



Why thermal control?





What about component life?

Electric

- Motor 8,000-35,000hrs
- High power electrics? Probably by inspection / long life?
- Propeller by inspection
- Batteries lifed 1,000-4,000 cycles
  - Degradation in aircraft use not well understood
  - Recycling capability in development

IC

- Engine TBO 1,200-2,400hrs
  - Technology well understood
  - Costs high ~5p/kW/hr, or £9/kW/year
- Propeller by inspection

Battery costs: per hour based on battery life

		1000cycle	2000cycle	4000cycle
Class	**Representative aeroplane**	**Bat/hr**	**Bat/hr**	**Bat/hr**
SSDR	**Chevvron**	£20.86	£10.43	£5.22
Micro-2	**Easy Raider 912**	£65.94	£32.97	£16.49
SE Light	**Europa XS**	£62.66	£31.33	£15.67
SE Heavy	**Cherokee**	£111.66	£55.83	£27.91

What about energy costs?

AVGAS (UK Prices) ~£1.70/litre = £0.05/MJ

AVTUR ~£0.80/litre = £0.02/MJ

UK wholesale electricity = £0.01/MJ

Already shown electric propulsion 26% of IC energy use.

Energy Cost Calculation…

- Comparison per MJ **used** (now, piston engine)..
  - 5p piston
  - 2p turbine

  - 0.26p electric

So SEP/MEP →CEP/DEP: 0.26/5 = 0.052. About 5% present energy bill.

And SET/MET → CEP/DEP: 0.26/2 = 0.13. About 13% present energy bill.

Energy Cost Calculation…

		Typical Fuel burn	AVGAS Cost	Equivalent Electricity Cost
Class	**Representative aeroplane**	**Litres/hr**	**£/hr**	**£/hr**
SSDR	**Chevvron**	10	17	0.85
Micro-2	**Easy Raider 912**	14	24	1.20
SE Light	**Europa XS**	18	31	1.55
SE Heavy	**Cherokee**	30	51	2.55

Total battery + fuel costs for battery cycle life

		1000cycle	2000cycle	4000cycle
Class	**Representative aeroplane**	**£/hr**	**£/hr**	**£/hr**
SSDR	**Chevvron**	£21.71	£11.28	£6.07
Micro-2	**Easy Raider 912**	£67.14	£34.17	£17.59
SE Light	**Europa XS**	£64.21	£32.88	£17.22
SE Heavy	**Cherokee**	£114.21	£58.38	£30.46

Probable total running costs

Assuming non engine costs equal usual engine fuel costs – nearest £5/hr

		1000cycle	2000cycle	4000cycle
Class	**Representative aeroplane**	**£/hr**	**£/hr**	**£/hr**
SSDR	**Chevvron**	£40	£30	£25
Micro-2	**Easy Raider 912**	£90	£60	£40
SE Light	**Europa XS**	£95	£65	£50
SE Heavy	**Cherokee**	£165	£110	£80

In summary then…

(1) Electric light and microlight aeroplanes are possible, at any scale – but not for all existing types.

(2) Initial investment is mainly in batteries – 3-10 times hull value per battery set.

(3) Endurance will be shorter than with conventional aeroplanes: typically 25-50%.

(4) Economics depend upon battery cycle life.

- 1000 recharge cycles uneconomic
- 2000 recharge cycles about break even
- 4000 recharge cycles, looks good

(5) Make the batteries cheaper, everything improves.

Will electric aircraft be environmentally "better" ?

Greenhouse gases – YES.

- AVGAS 0.072 kg CO_2/MJ
- UK Electricity 2018: 0.097kg CO_2/MJ
- But electric aircraft uses ~26% of energy

  => Electric aircraft has $\frac{0.097}{0.072} \times 0.26$~35% of Carbon footprint.

Anything else – NO

- Only about 5% of Li-Ion batteries presently recycled
  - Possible, but ~3 times as expensive as new.
- Lithium mining is environmentally problematic
- Many other chemicals involved
  - Massive wastage production wastage

What don’t we know?

- How to manage motor and battery thermal control
  - Thermal load on motors drives maximum power settings
  - Liquid cooling of electric motors likely to be essential
- Optimal crashworthiness and fire protection strategies
- The certification basis (amendments to Section S, VLA & part 23)
  - Including test methods
  - Measurement of battery life / capacity, and relationship to performance
- Best flying practices
  - Powerplant control and management
  - What emergencies can occur, and how to handle them?
- How to convert between electric trained pilots & IC pilots…

Thanks for listening

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