Electric Taxiing – and Electric Machine Technologies for Aerospace

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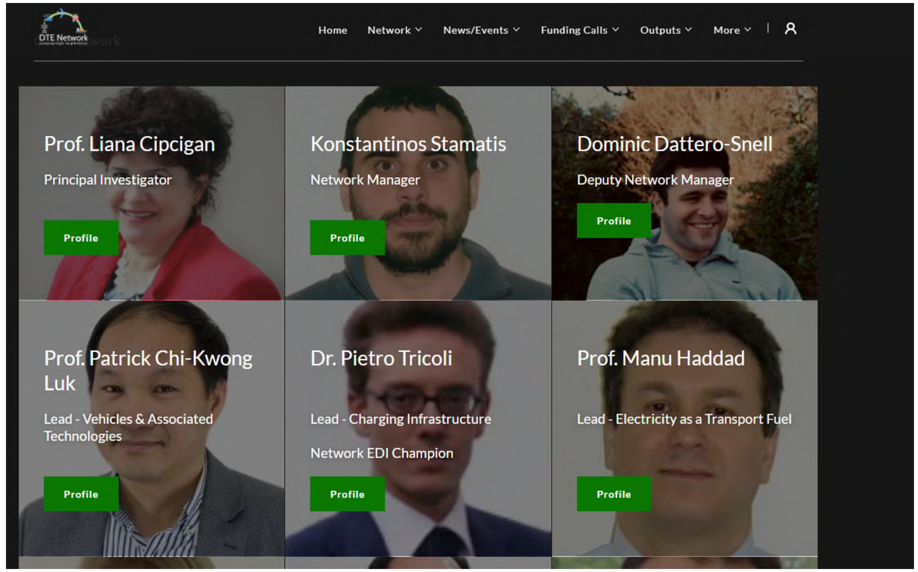
DTE Network

Decarbonising Transport through Electrification, A whole system approach Network+

UKRI Engineering and Physical Sciences Research Council



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How to address the aviation transport challenges **today** (Flightpath 2050 Vision):

- 75% reduction in CO_2, 90% reduction in NO_x, 65% reduction in noise (2000 base line)
- All aircraft ground movements are emission-free
- 90% of travellers within Europe are able to complete their journey, door-to-door within 4 hours

- Cost efficiently

Theme 1. Electric Powertrains

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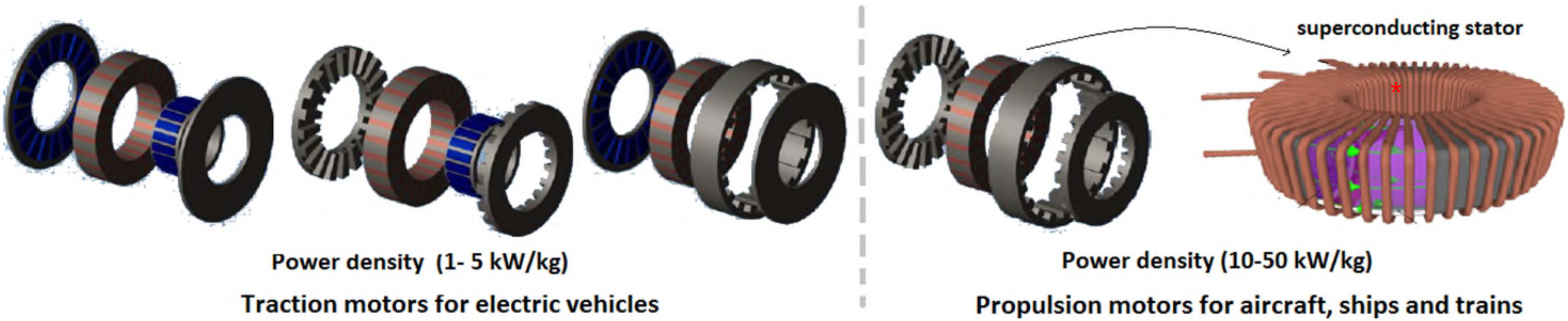
Fundamental research in electric powertrains – A modular topology

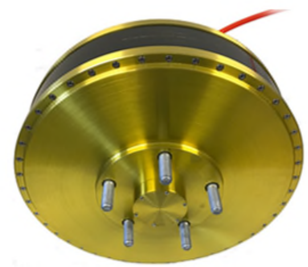


*P.C.K. Luk, “Superconducting machines — The enabling technology for future electric propulsion in aircraft”, IEEE International Conference on Power Electronics Systems and Applications - Smart Mobility, Power Transfer & Security, Dec 2017, pp1-7

Theme 2: Connected Autonomous Vehicles (CAV)

A Modular framework to build CAV

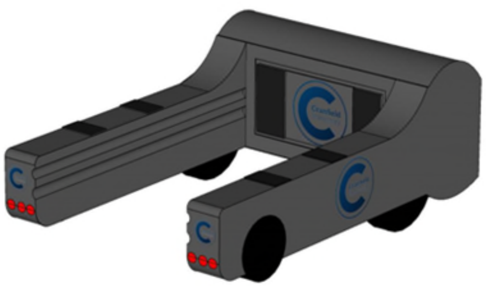
(a) Autonomous motor-driven platform



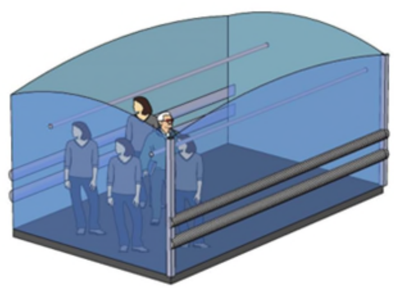
(b) Rare-earth PM in-wheel motor

(c) Ferrite traction PM motor

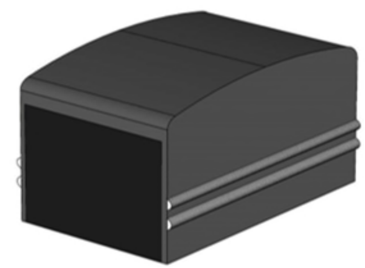
Cranfield's Modular Autonomous Electrified Platform and the Traction Motor Technologies



(a) Autonomous motor-driven platform



(b) People mover capsule

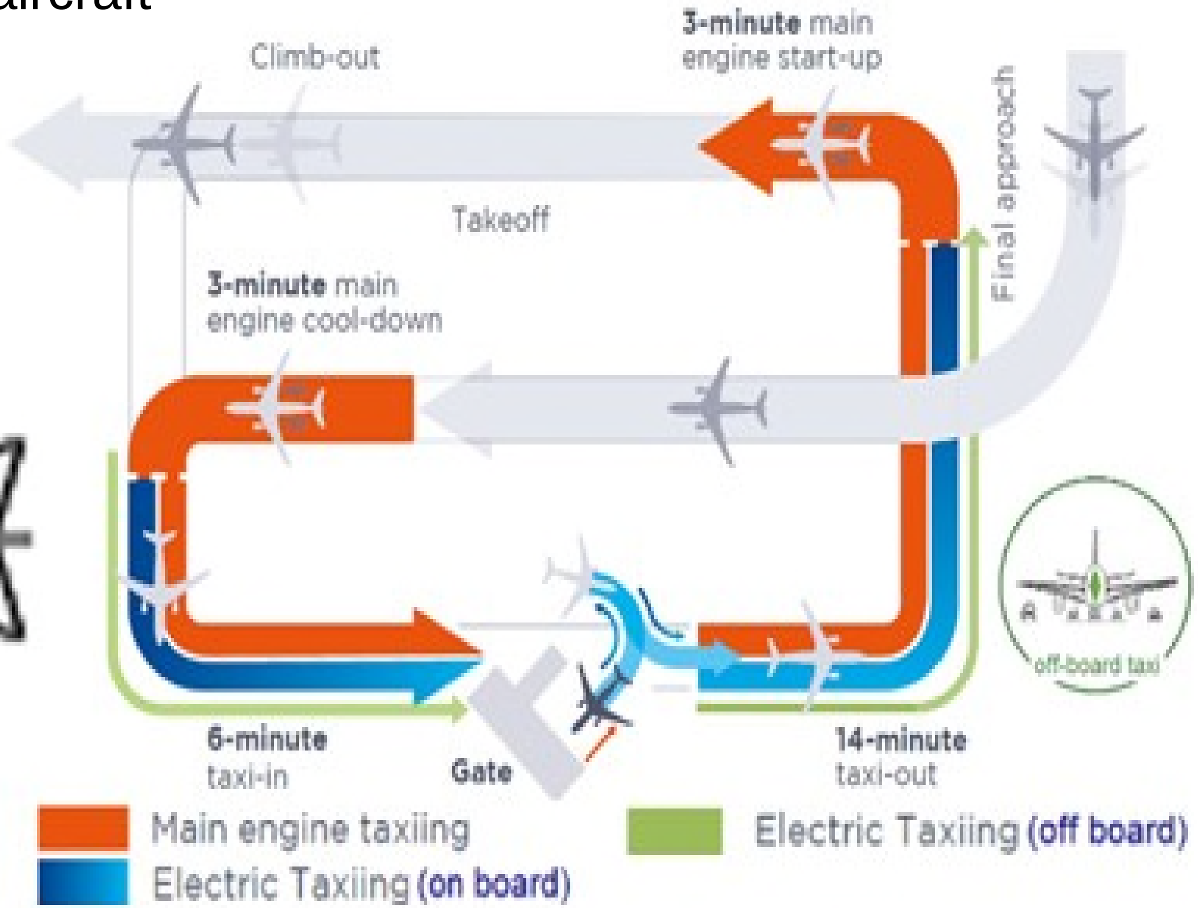


(c) Cargo capsule

Mobility as a Service (MaaS)

Technology Demonstrators for e-taxiing (for commercial airliners and small electric aircraft

(a) Small electric/ hybrid aircraft



(b) Electric taxiing - On-board & off-board

Cranfield's study on electric taxiing

- Systematic E-taxiing studies by Cranfield (staff and students) since 2014
- The environmental case for zero emissions e-taxi of short haul airliners has been demonstrated as feasible using on-board systems retrofitted to drive current airliners main landing gear wheels by a Cranfield study [1]. A net fuel saving is predicted, as well as the local ground emissions eradication.
- Up to £1/4M fuel cost could be saved per annum per aircraft (A320 size)

[1] Benefit and Performance impact analysis of using hydrogen fuel cell powered e-taxi system on A320 class airliner" Liu, Zihang, Stockford, J., Lawson C. P., The Aeronautical Journal, accepted for publication October 2018.

Overview of state-of-the-art electric taxiing systems I

- Currently electric powered on board taxi solution on the market is wheel-tug [2]. There has been minimal uptake of the technology, and there are concerns that this nose-wheel driven solution lacks the necessary traction for wet runway operation.
- Safran and Airbus had announced commercialisation of a main-gear-wheel driven solution [3]. This solution is not zero-emission. It generates electricity by burning kerosene in the aircraft's auxiliary power unit. The programme was cancelled.

[2] http://www.wheeltug.com/

[3] https://www.safran-landing-systems.com/media/airbus-and-safran-market-electric-taxiing-system-a320-family-20170621

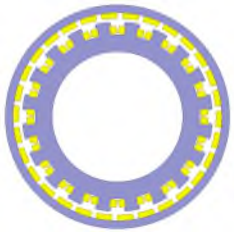
Overview of state-of-the-art electric taxiing systems II

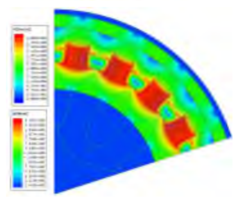
- TaxiBot is the most advanced and only certified off-board system currently on the market [4]. It has several drawbacks:
  - Only suitable for pushback and initial taxi out
  - Unsuitable for taxi in
  - Manual operation
  - Potential long delays due to connecting and disconnecting

[4] http://www.taxibot-international.com/

Green (Electric) Taxiing System

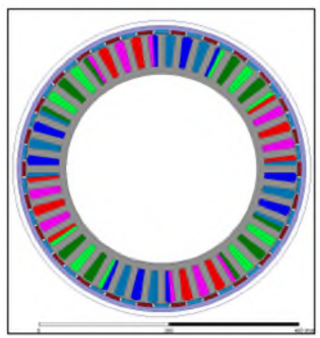
Parameters	Value	Unit	Value
Stator Outer Diameter (Dso)	360	mm	360
Stator Inner Diameter (Dsi)	317	mm	317
Rotor Outer Diameter (Dro)	305	mm	305
Axial Length (le)	100	mm	100
Air gap Length (g)	6	mm	6
Number of Poles (p)	20		20
Number of Slots (q)	30		30
Rated Torque (T)	1500	Nm	1500
Rotating Speed	320	rpm	320





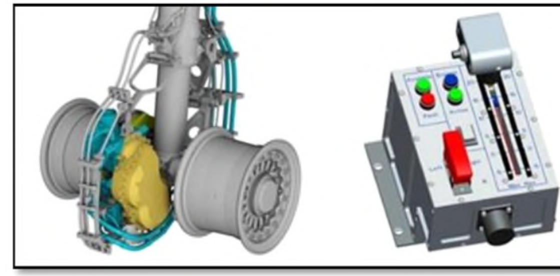
Partial Superconducting motor

Machine Parameters	Value	Unit
Rotor Outer Diameter (D_{ro})	450	mm
Stator Outer Diameter (D_{so})	423.7	mm
Stator Inner Diameter (D_{si})	298	mm
Air gap Length (g)	2	mm
Stack (axial) length	160	mm
Number of Poles (p)	52	
Number of Slots (q)	48	
Rated Torque (T)	1500	Nm
Motor efficiency	90	
Rotating Speed	320	rpm
Lamination (stator and rotor)	59.5	kg
Copper windings	11	kg
PM (NdFeB)	6.6	kg
Machine Active total weight	77.1	kg

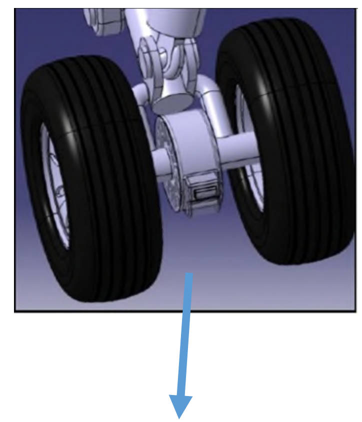


Rare-earth PM motor

(Honeywell and Safran, 2013)



Previous Cranfield study on in-wheel configuration



Autonomous taxi-bot - building on a Mobility As A Service (MAAS) concept)

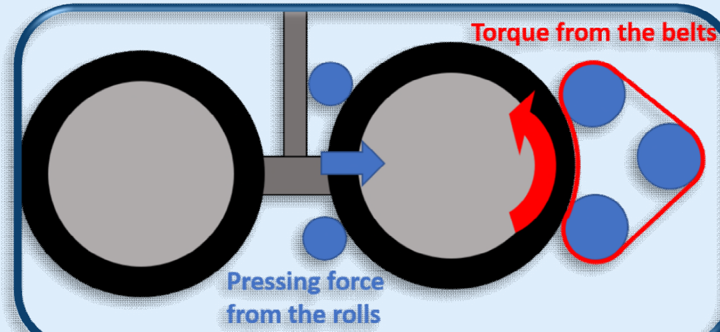
Study 1 – Mechanical and energy design of off board e-taxiing

Towbar tractors: Stress on the landing gear

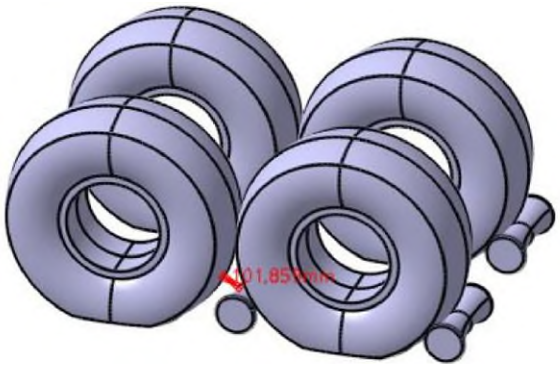
Lifting the landing gear: Takes time

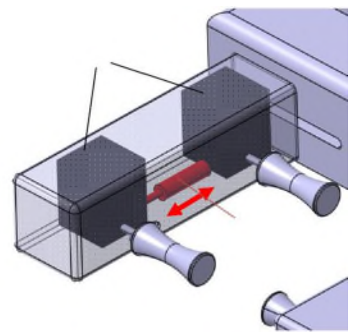
Transmission of the power directly to the wheels of the Main Landing Gear

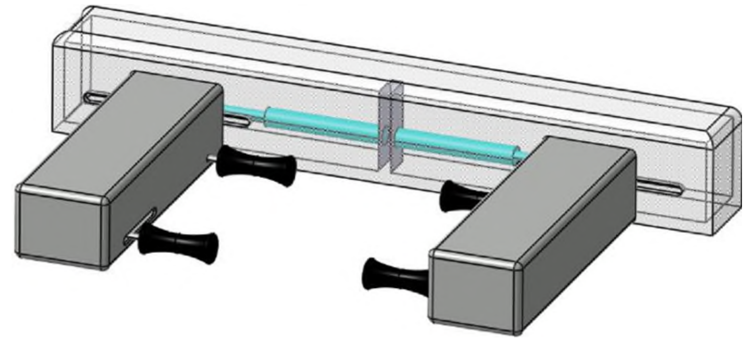
- Friction belt to transmit the power from the motor
- Rolls to ensure sufficient traction

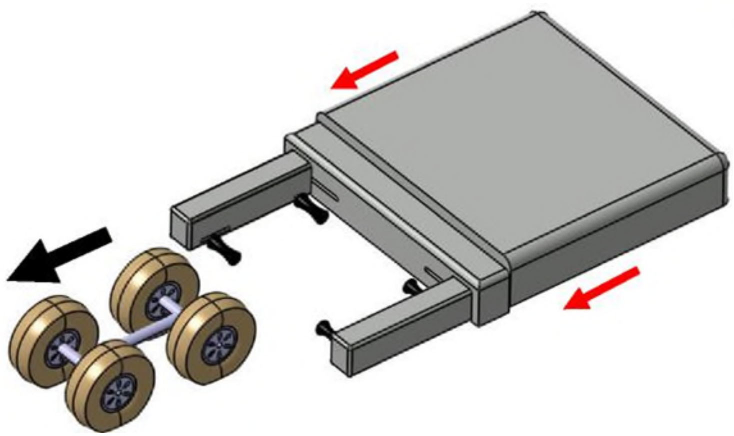


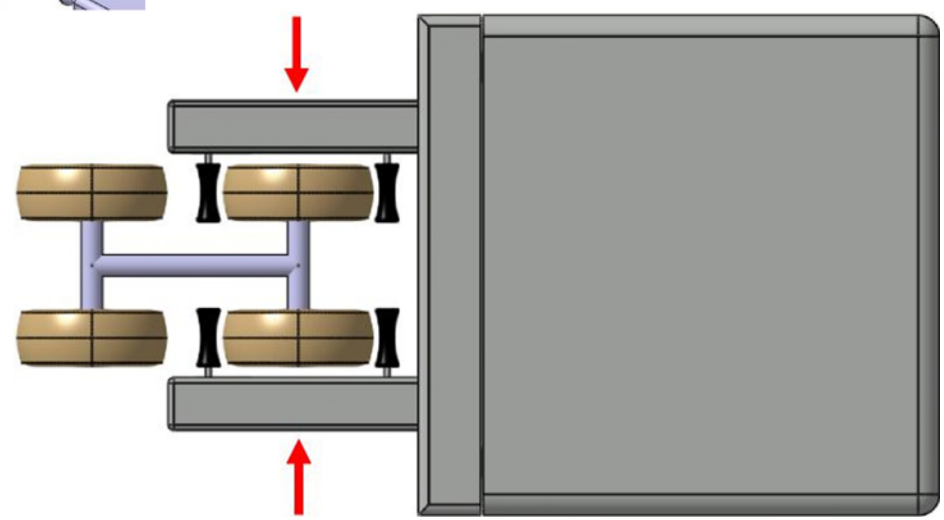
Initial design without belt





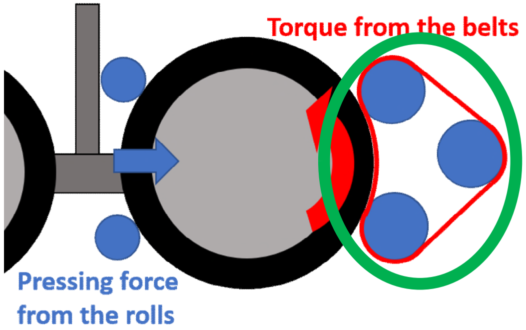


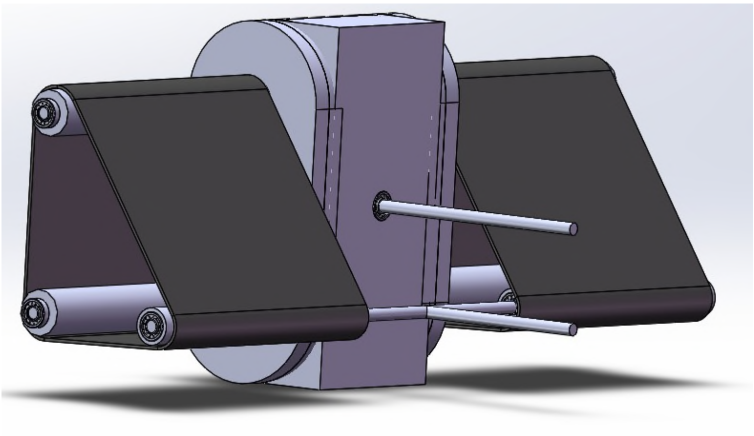


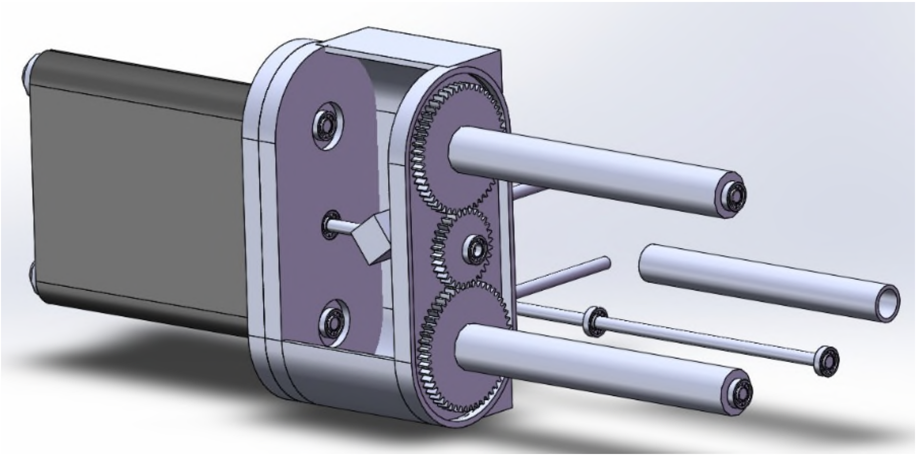


Mechanical design – Friction belts

- The power comes from the motor through the middle axle.
- Differential separates it between the two belts
- Tension is assured by the back rolls

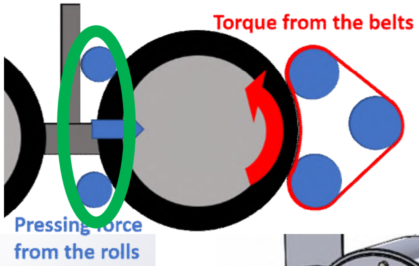


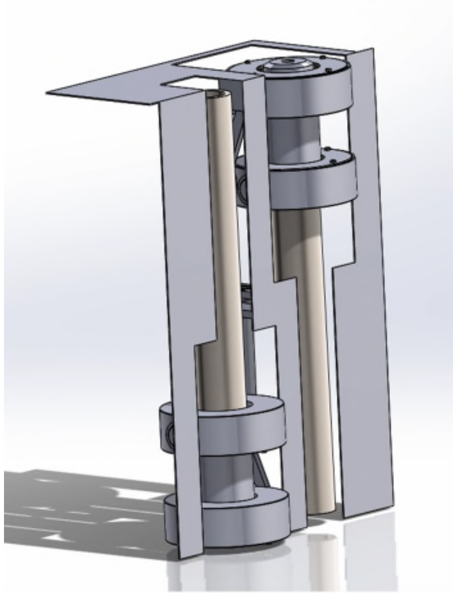




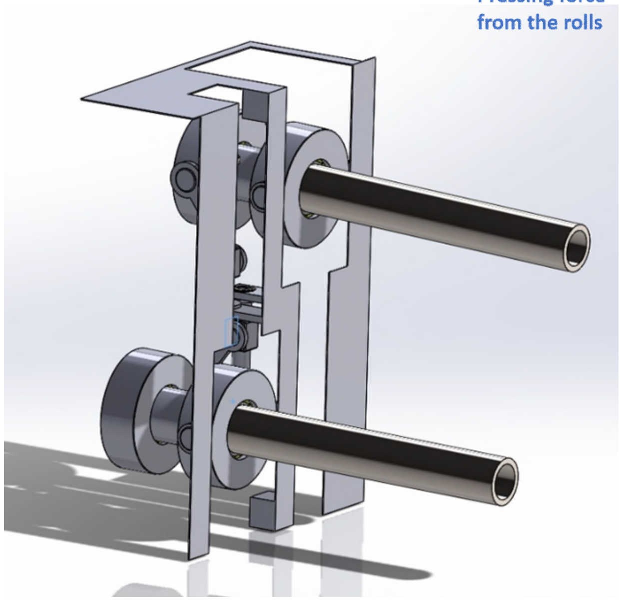
Mechanical design – Folding rolls

Folding rolls to access the front of the tyre in order to provide traction for the belts.

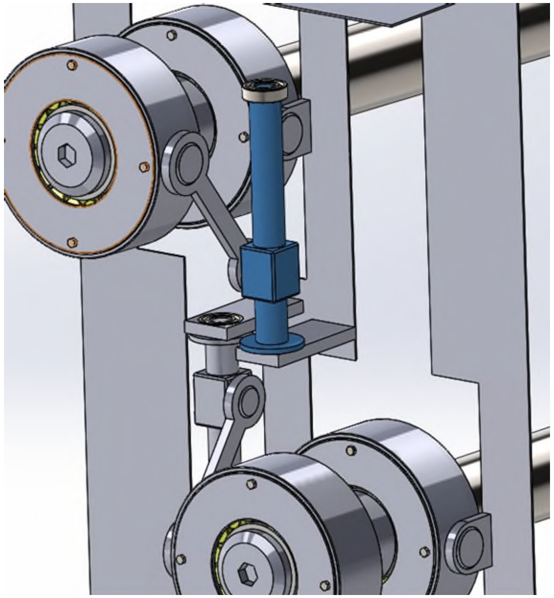




Folded view



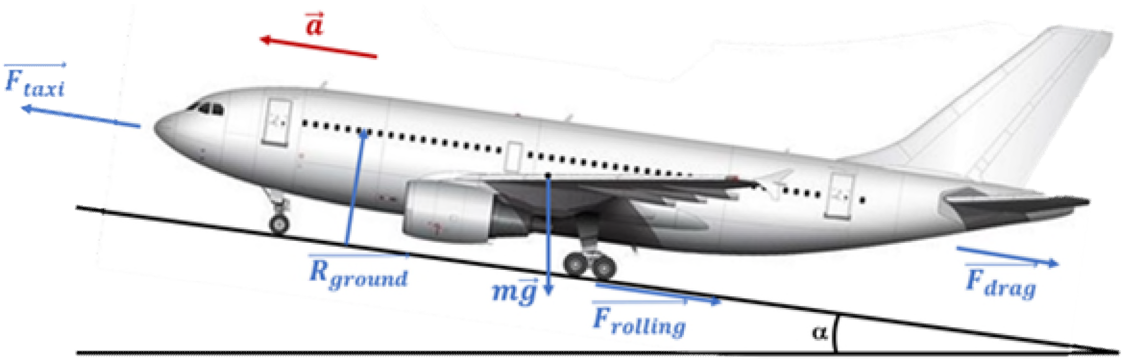
Unfolded view



Screw-Nut mechanism

Performances – Motor selection (use commercially available)

Top speed	23 knots (11.83 m/s)
Acceleration	0 to 10 knots (5.14 m/s) in 20s
Operability	1.5% slope 15 m/s wind



EMRAX 348	
Peak torque	1000 Nm
Continuous torque	500 Nm
Maximum speed	4000 RPM
Efficiency	92-98%

Tyre Dimension consideration

Main dimensioning criteria:

- Tyre size
- MLG width
- Lowest point of fuselage

Type	MLG width /m
737	1.125
747	1.538
777	1.955
A320	1.377
A380	2.101

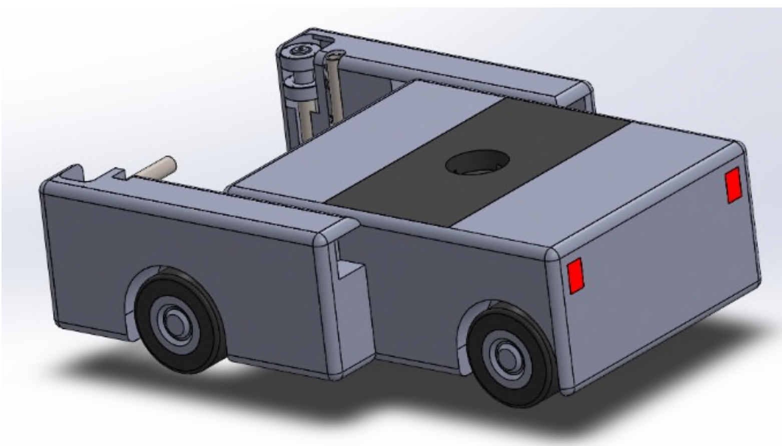
Type	Bottom of fuselage /m
737	0.91
747	2.08
777	3.58
A320	1.6
A380	4.66

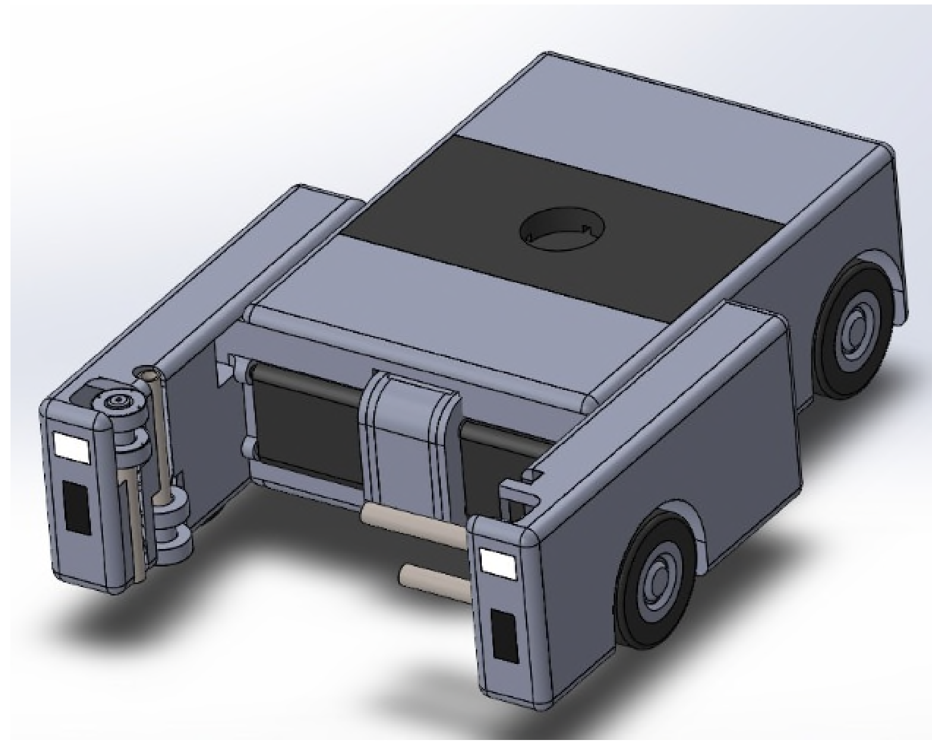
MAIN GEAR TIRE SIZE				
Type	Inflatable size /mm			
	Width		Diameter	
	Section	Shoulder	Centerline	Shoulder
737	355	305	1010	890
747	438	368	1238	1092
777	555	500	1368	1287
A320	450	405	1207	1137
A380	551	485	1444	1358

Mechanical design – Global assembly

Global assembly with the different parts

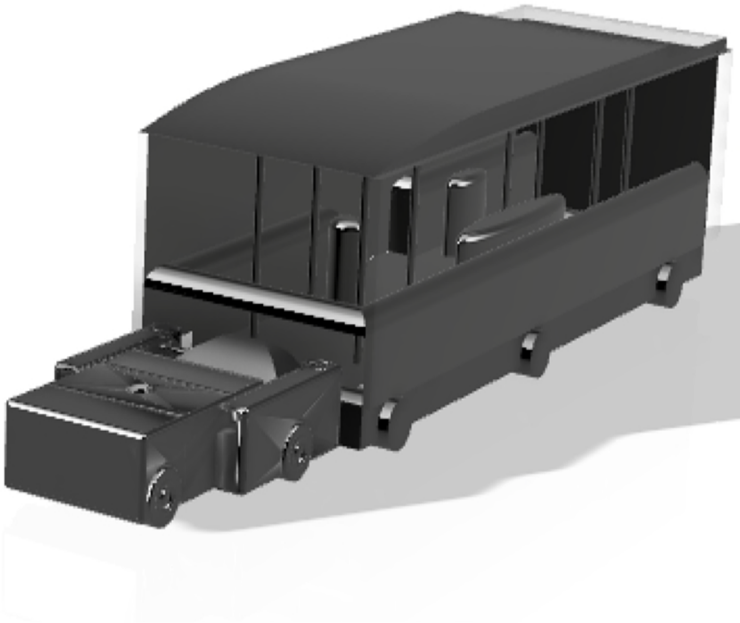
- Main body with battery and motor
- Power transmission with belts
- Sliding arms with folding rolls
- Lights, sensors, etc.



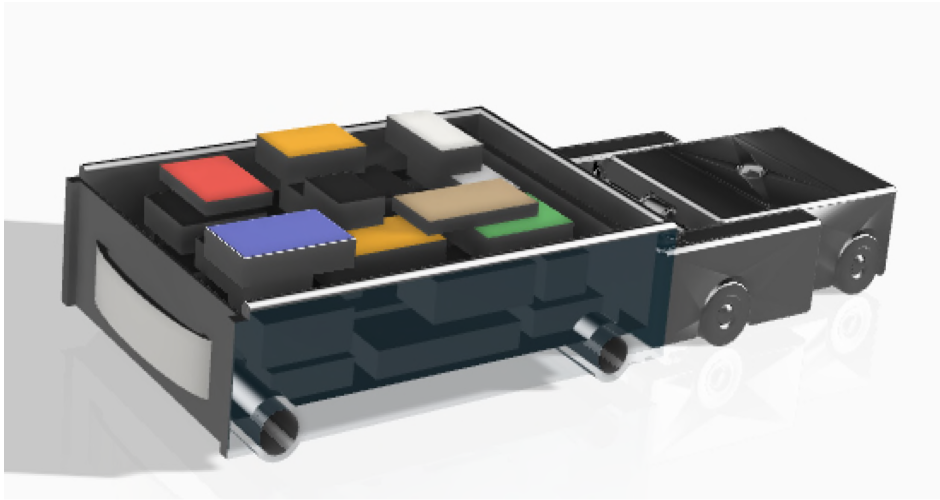


Same base vehicle for other airport ground operations

Passengers transportation



Cargo transportation



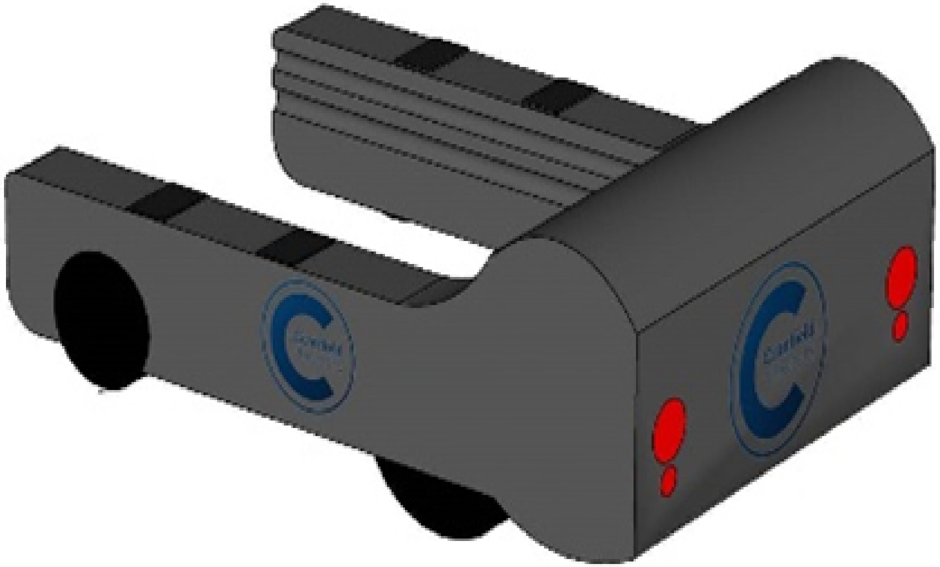
Study 2 - Concept exploiting autonomous vehicles for electric taxiing

Providing the aircraft Taxiing and Landing as a mobility service

Autonomous Electric Taxiing and Landing Vehicle System

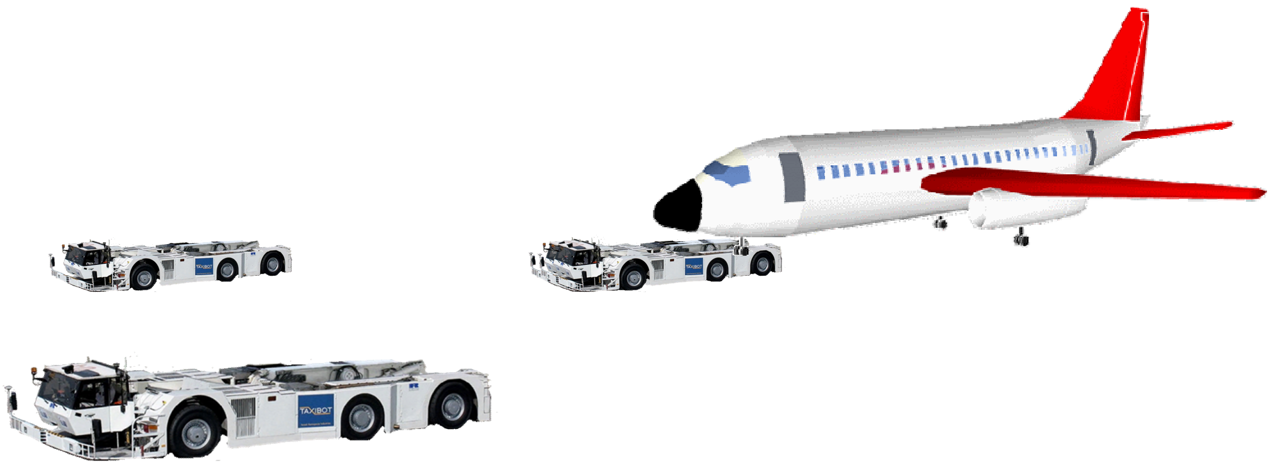
This new concept involves further study to verify the potential advantages such as energy saving, battery sizes and charging infrastructure.

Cranfield's Autonomous Modular Vehicle Platform

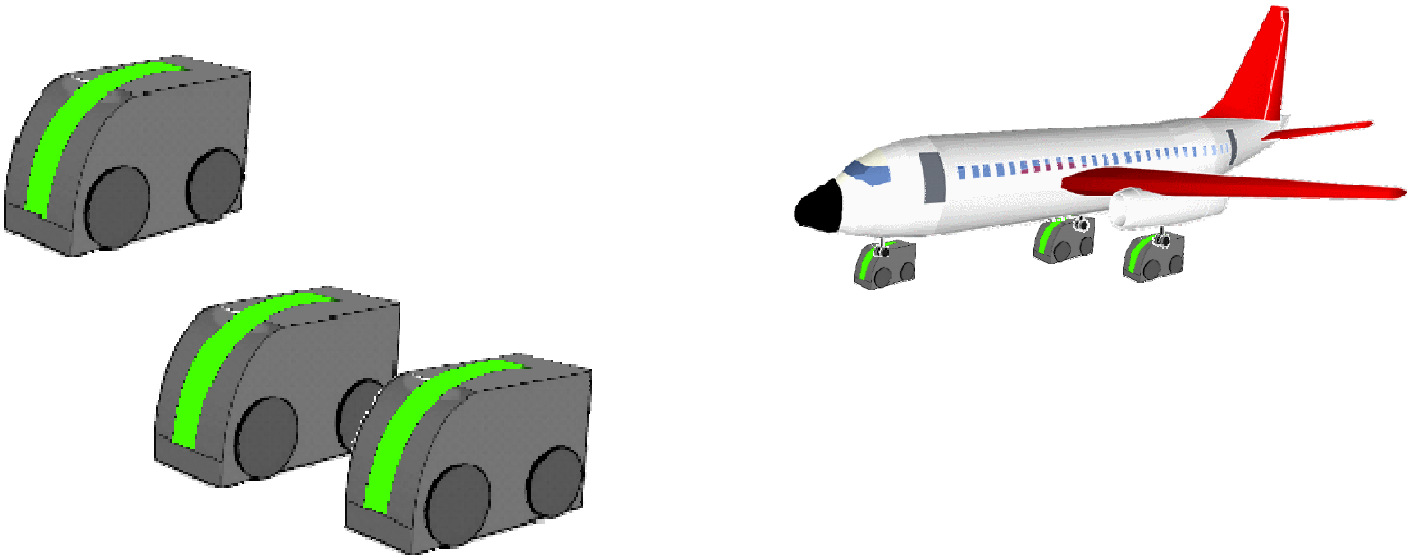


- Modular motor technologies
- Modular battery configuration
- Charging/discharging interface to grid
- Grid support
- Taxiing lock and unlock interface

State of the Art Electric Taxiing System

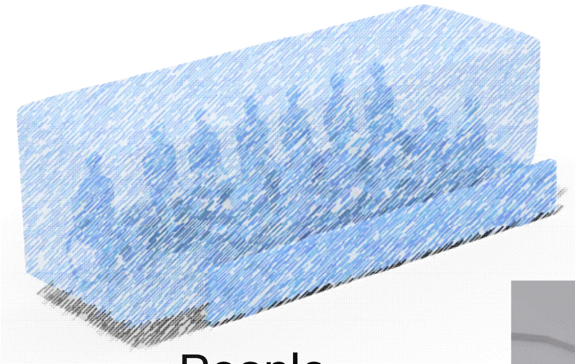


Cranfield Modular Electric Taxiing System

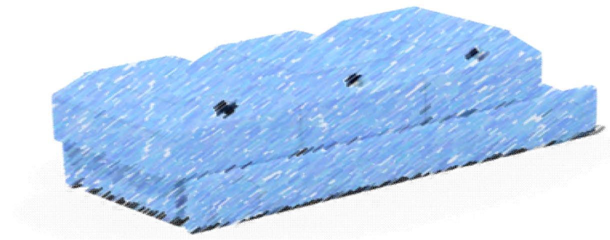


Mobility-as-a-Service (MaaS)

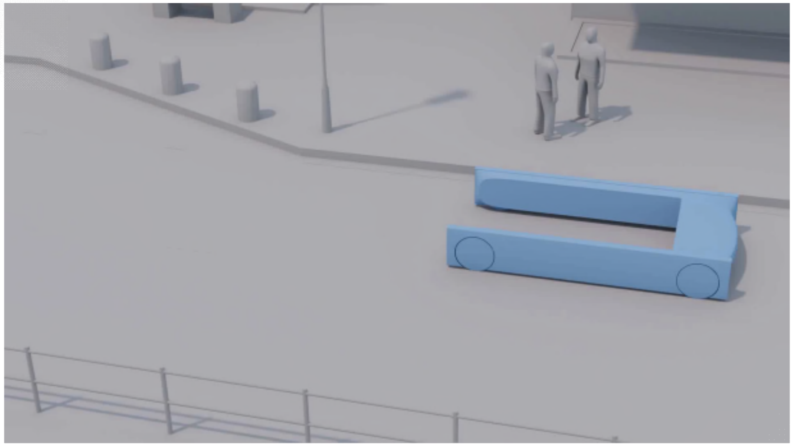
Driven by demands in European's 2050 Efficient Transportation targets: Every door to door journey within EU must be within **4 hours and CO2 free**

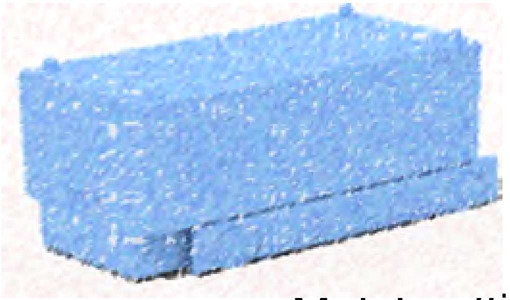


People mover

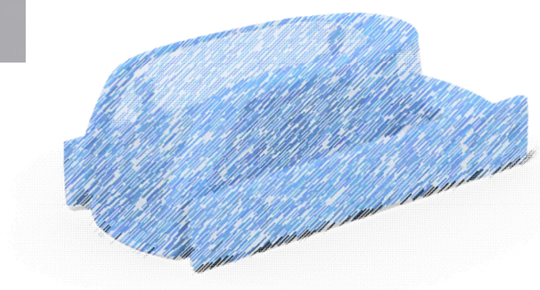


Luggage mover





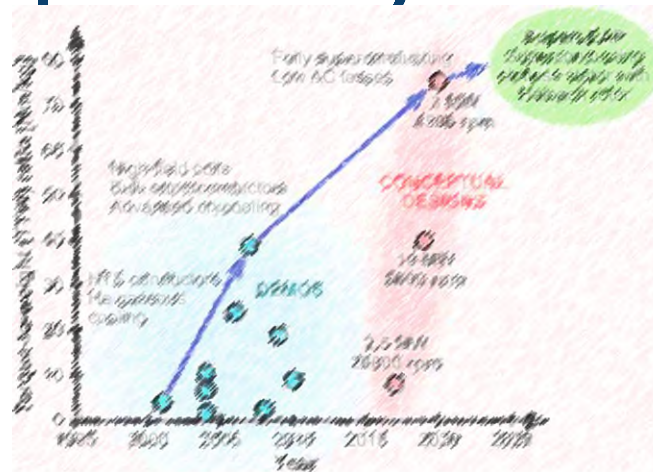
Mobile office



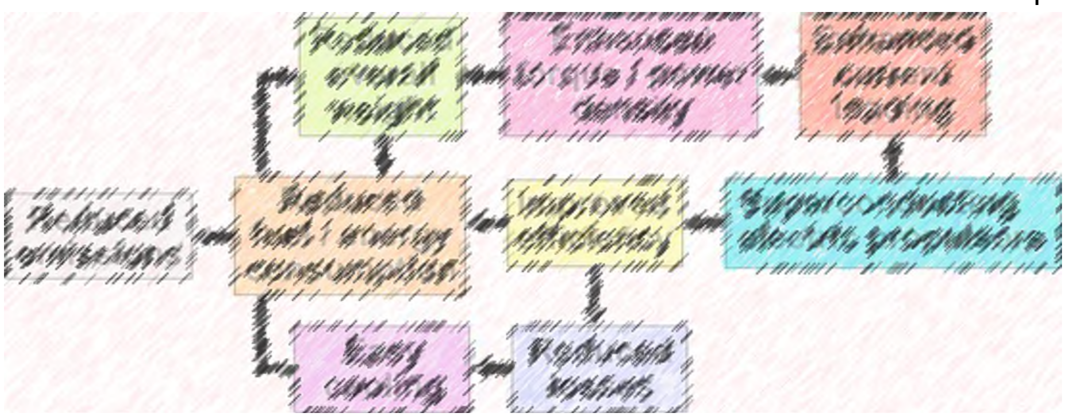
Premium VIP capsule

Superconducting Low-Emission Aircraft Propulsion System (SuperLEAPs)

Cranfield University BW-11 very large blended wing-body passenger transport aircraft

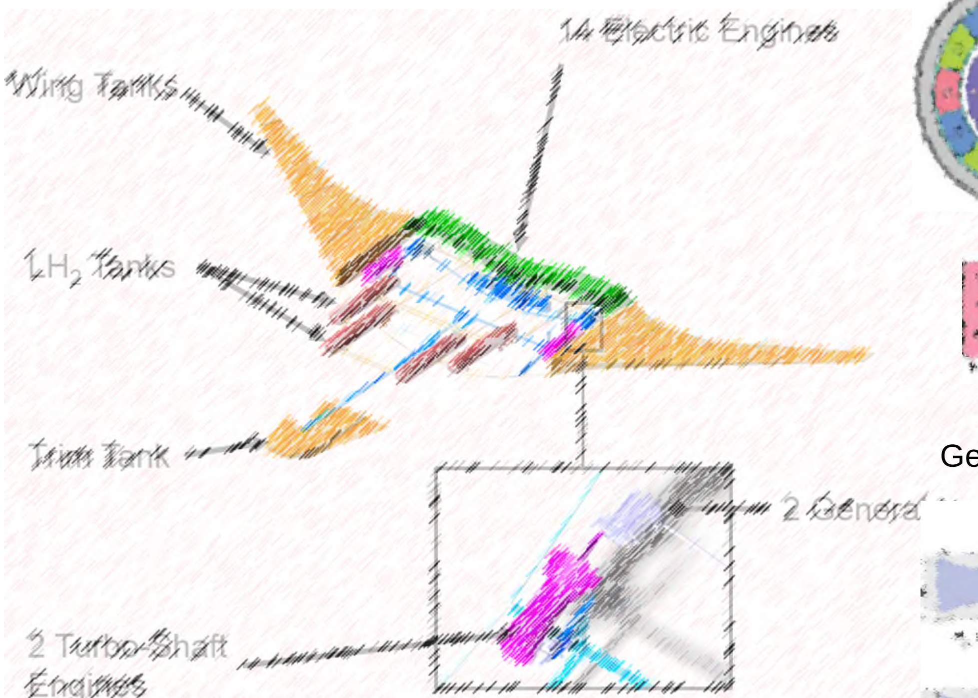


Advancements toward ultra-lightweight superconducting electrical machines with SuperLEAPS goal indicated

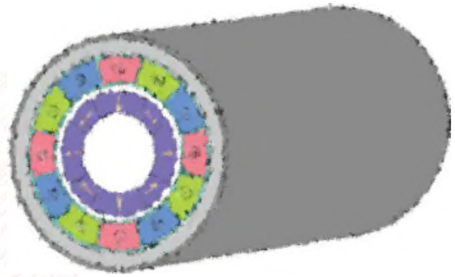


Overall design philosophy of improving general electric aviation using partially superconducting machines (SCMs)

SuperLEAPs – SCM and Power Converters

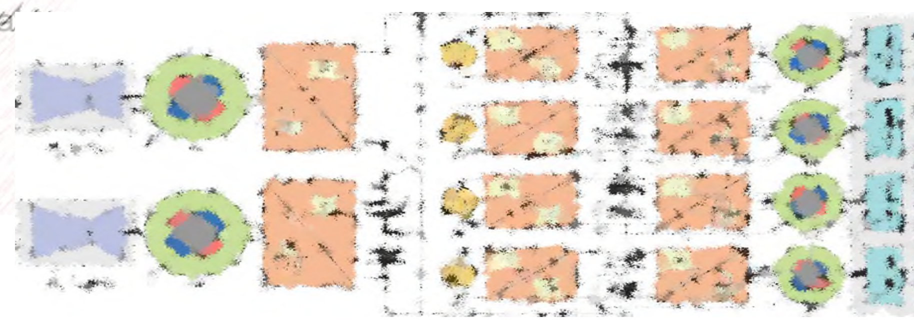


Cranfield University BW-11 very large blended wing-body passenger transport aircraft



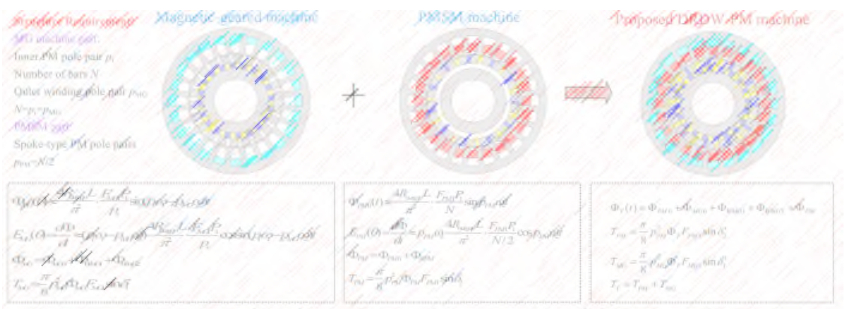
Cross-sectional view of the proposed slotless superconducting stator with ironless Halbach rotor

Generic fuel cell based drive system for a single propeller

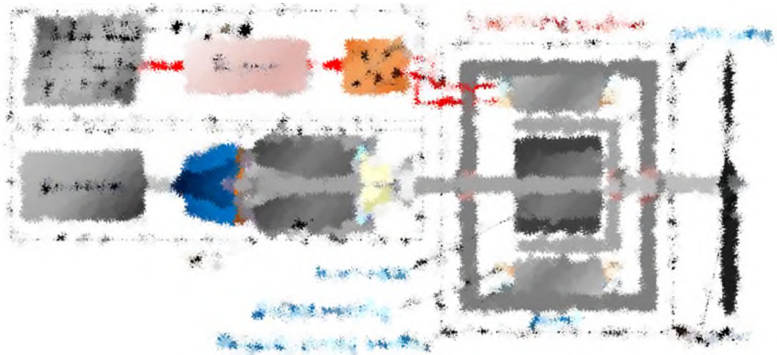


Modular distributed series-connected propulsion system with H2 fuel

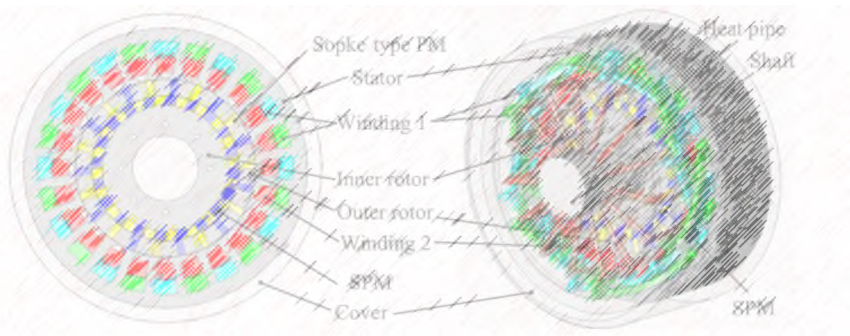
Novel hybrid drive for High Endurance UAV



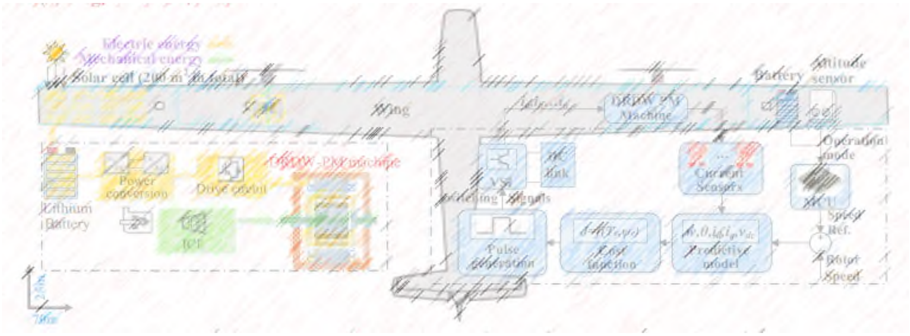
Operating principle decomposition of proposed DRDW-PM machine



Proposed DRDW-PM machine for hybrid power powertrain of HE-UAV.



Proposed radial DRDW-PM machine. (a) Cross view. (b) 3D model with heat pipes.



Schematics of power flow and control strategy of scale-HE-UAV.

Cranfield Energy and Power

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