IMOTHEP
GETTING HYBRID ELECTRIC

Superconducting motor associated with cryogenics power electronics for aircrafts

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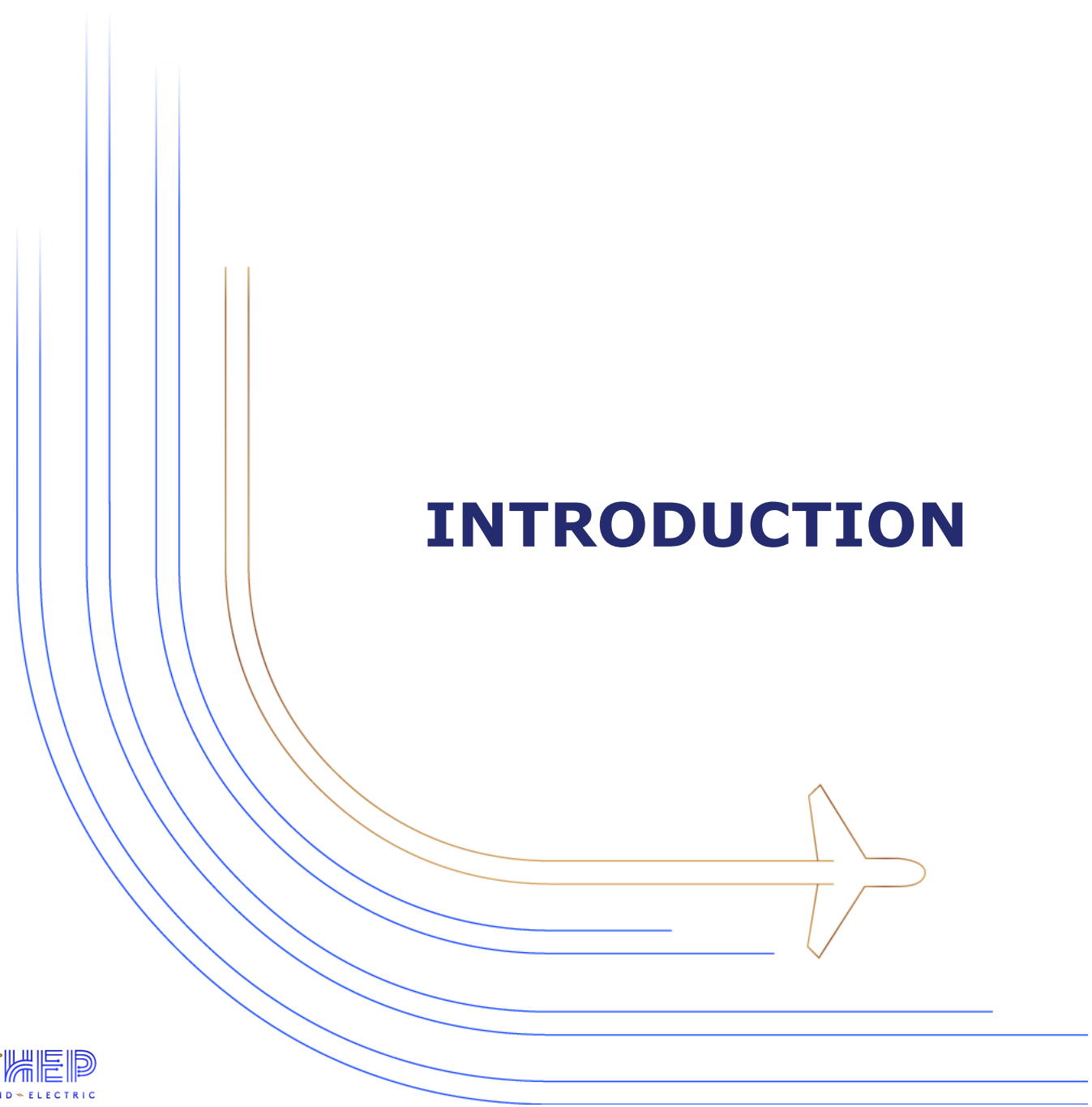
INTRODUCTION



IMOTHEP's top level ambition

Imhotep - Egyptian architect, doctor and philosopher
A great and innovative builder…

"Investigation and Maturation of Technologies for Hybrid Electric Propulsion"

- **H2020 project (**Call 2019 "Mobility for Growth" - "towards a hybrid/electric aircraft")

- **Achieving a key step in assessing potential benefits of HEP for emissions reductions of commercial aircraft**
- **Building the overall European development roadmap for HEP**

- **First level objectives**
  - Identifying propulsion architecture & aircraft concepts benefiting from HEP
  - Investigating technologies for HE power train architecture and components
  - Analysing required tools, infrastructures, demonstrations and regulatory adaptations for HEP development
  - Synthesising results through the elaboration of the development roadmap for HEP

IMOTHEP project

- **Four-year research project (2020-2024)**
  - Coordinated by ONERA
- **29 partners**
  - **9 European countries + international partners from Canada**
- **10.4 M€ EC funding** (+ contribution of international partners)

ONERA THE FRENCH AEROSPACE LAB

UP

SAFRAN

DLR

Avio Aero

LEONARDO AIRCRAFT

CIRA Centro Italiano Ricerche Aerospaziali

AIRBUS

AIT Austrian Institute of Technology

Bauhaus Luftfahrt Neue Wege

CHALMERS UNIVERSITY OF TECHNOLOGY

EUROCONTROL

GKN AEROSPACE

INCAS National Institute for Aerospace Research "Elie Carafoli"

Łukasiewicz Institute of Aviation

ITP Aero

ISAE SUPAERO

KIT

MTU Aero Engines

nlr

Politecnico di Bari

University of Nottingham UK | CHINA | MALAYSIA

University of Strathclyde Glasgow

UNIVERSITÉ DE LORRAINE

NRC·CNRC

Project's scope & targets

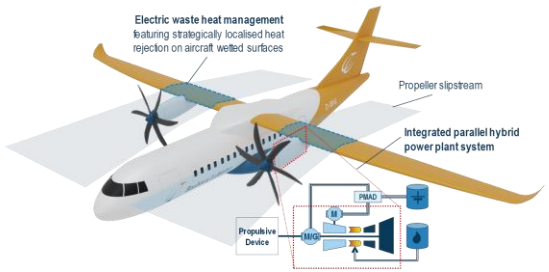
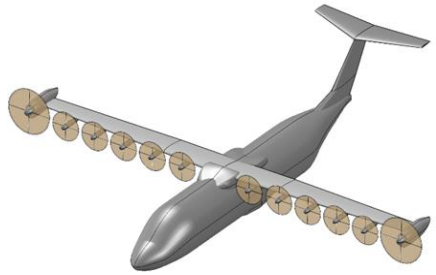
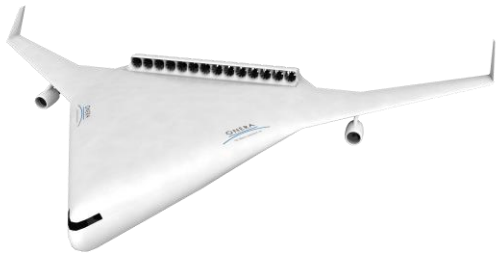
- **Reference missions**
  - **Short/medium range:** minimum segment for a significant impact on aviation emissions
  - **Regional:** more accessible, potential intermediate step toward SMR

Mission	PAX	Speed	Range
Regional	40	Mach 0,4	600 nm (typ. 200 nm)
SMR	150	Mach 0,78	>= 1200 nm (typ. 800 nm)

  - EIS: 2035+
- **Technological scope**
  - Central focus on thermal hybrid with drop-in fuel
    + some investigations on fuel cells at conceptual level (aircraft + fuel cell specific issue for aircraft)
  - Main focus on conventional conductivity
    + Exploration of superconductivity as a potential enabler
- **Ambition :** reaching 10% more emissions reductions than Clan Sky 2 targets with conventional technologies

Project's suporting configurations

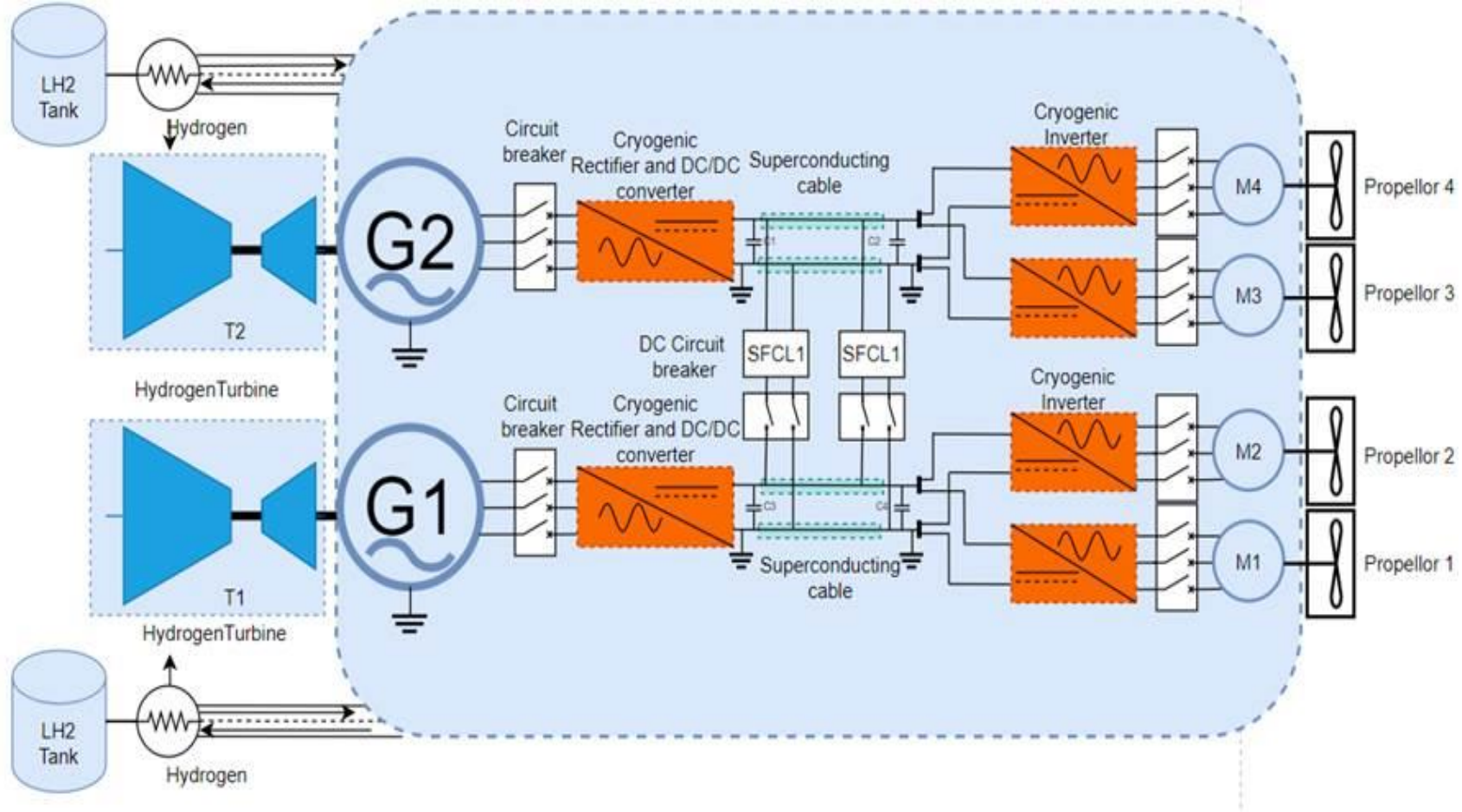
- Build-on / complement previous studies (e.g. CS2, CENTRELINE,etc.)
- Explore a range of architectures with consistent assumptions

	Conservative	Radical
Regional	 Electrically assisted turboshaft	 Turboelectric + DEP + wing-tip propeller
SMR	 Tube & wing, turboelec, DEP (from CS2)	 BWB, turboelectric, DEP, BLI

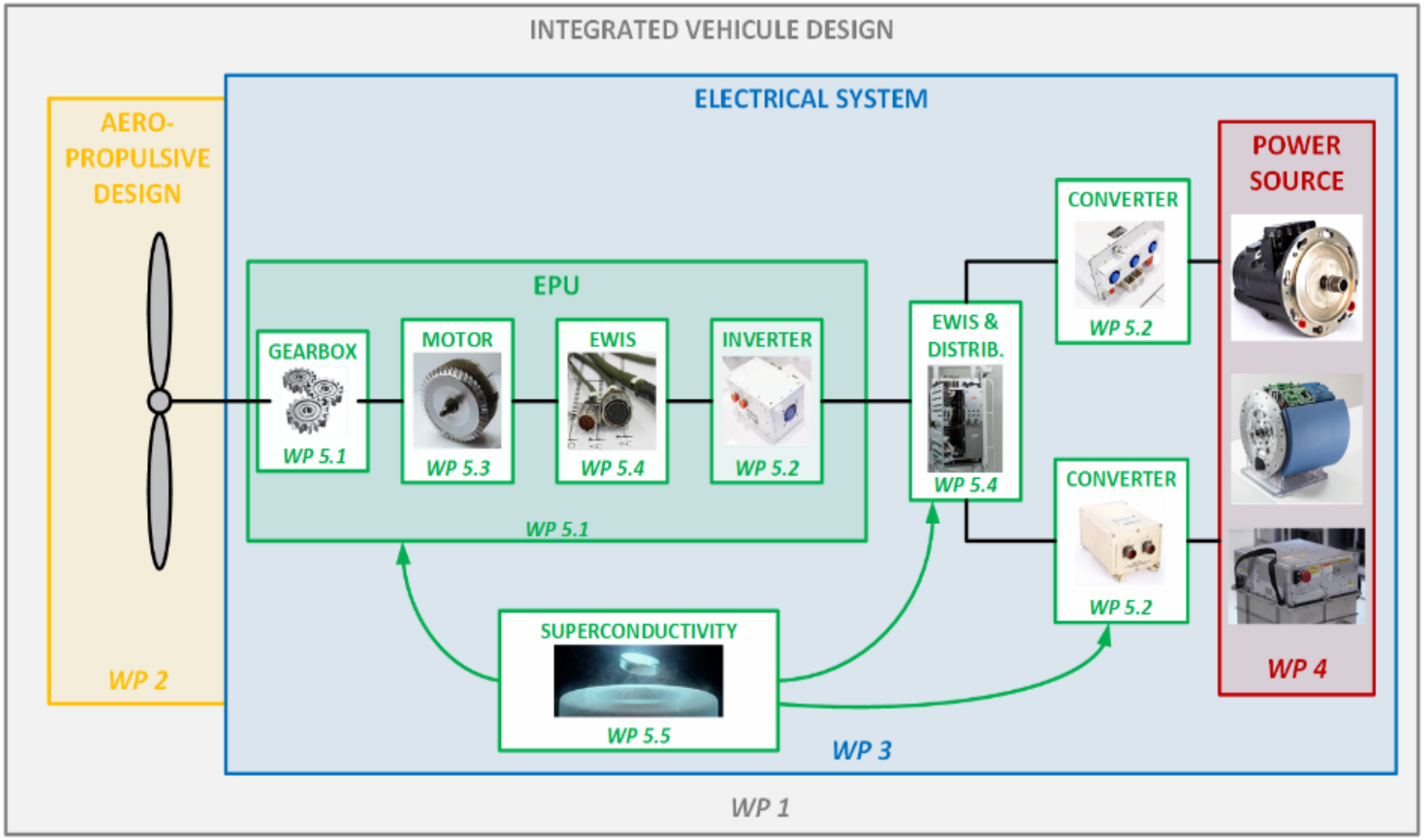
Initial supporting configurations

General description of the studied system

All system is cooling by LH2, number propeller not fixed



WP5 PERIMETER



Hypothesis for WP5.5

Overall description of the approach and hypothesis

Electrical machine Hypothesis

- The operating temperature is 20°K ➔ liquid hydrogen.
- Full superconducting synchronous motor is considered to provide best performances.

Power electronics Hypothesis

- The operating temperature is between 50°K to 70°K.
- Semi-conductor technology: IGBTs have sufficient ratings and good performance at cryogenic temperatures ➔ the most suitable device to build the cryogenic inverter.

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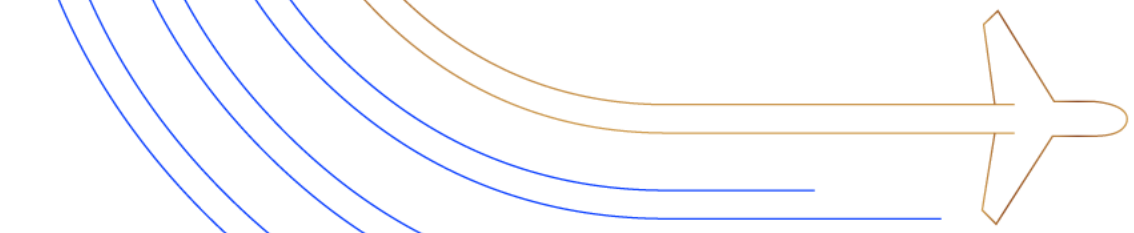
SUPERCONDUCTING MOTOR AND GENERATOR



Superconducting motor or generator

Synthesis of the main results for the superconducting

Superconducting EM Preliminary results (Active parts)

- Motor with high airgap ➔ 2 Cryostats

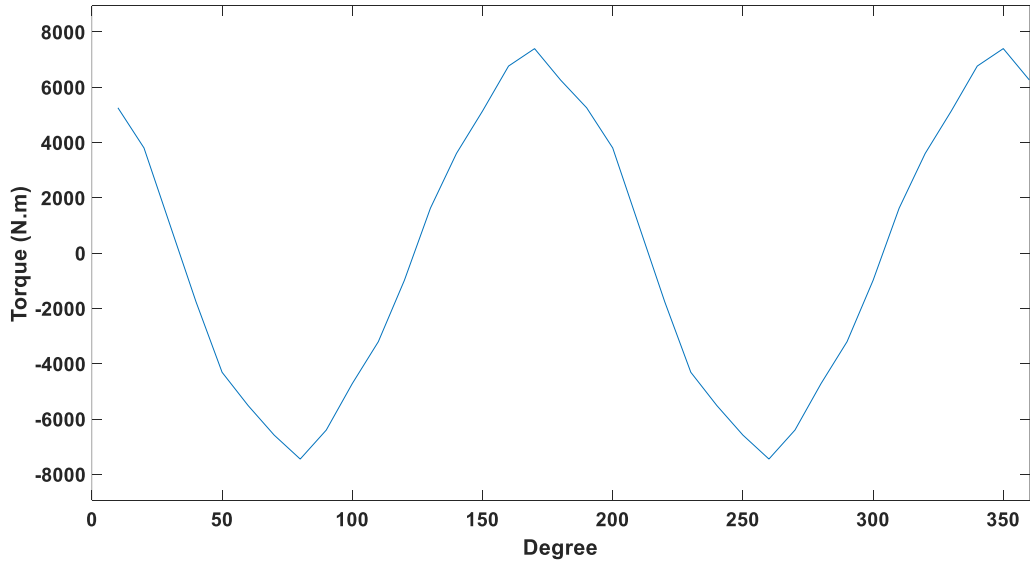
Parameter	Value	Unit
Length	200	mm
Radius of the machine	150	mm
Power	2.9	MW
Power to Mass ratio	54	kW/kg
Efficiency	99.7	%

- Motor with small airgap ➔ 1 Cryostat

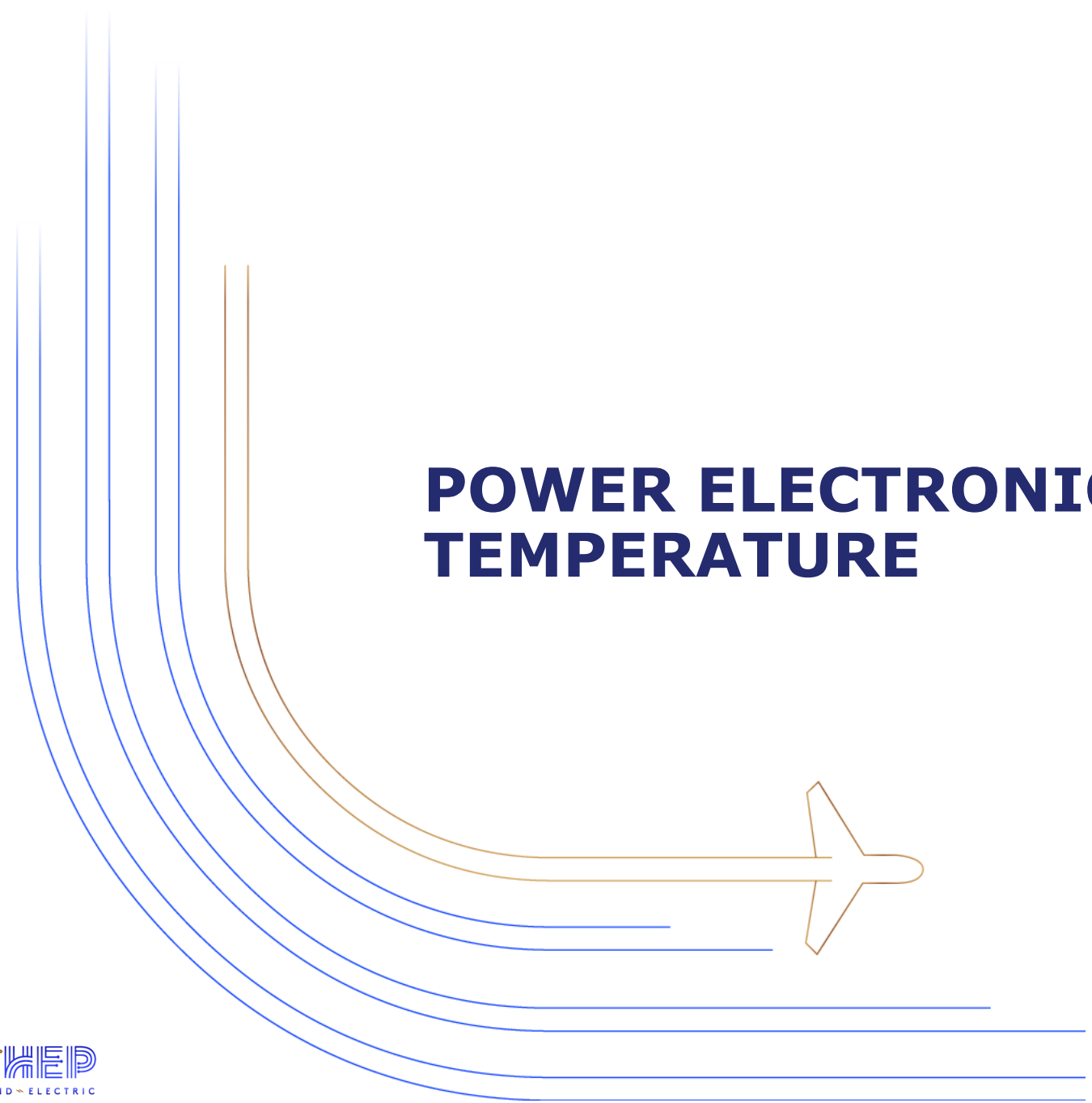
Parameter	Value	Unit
Length	200	mm
Radius of the machine	140	mm
Power	2.6	MW
Power to Mass ratio	51	kW/kg
Efficiency	99.7	%

- Quick estimate of the amount of cryogenic fluid results in a consumption of 55kg/h of liquid hydrogen

Parameter	Value	Unit
Length	200	mm
Radius of the machine	140	mm
Thickness of backiron	20	mm
Stator slot depth	10	mm
Number of stator slot	6	
Airgap	5	mm
Rotor slot depth	10	mm
Number of rotor slot	8	
Thickness of rotor backiron	10	mm
Current density in stator	100	A/mm^2
Bmax on stator coil	1.8	T
Current density in rotor	500	A/mm^2
Bmax on Rotor coil	1.08	T
Power	2.6	MW



POWER ELECTRONICS AT LOW TEMPERATURE



Cryogenic power electronic

Synthesis of the main electronic component for cryogenic use

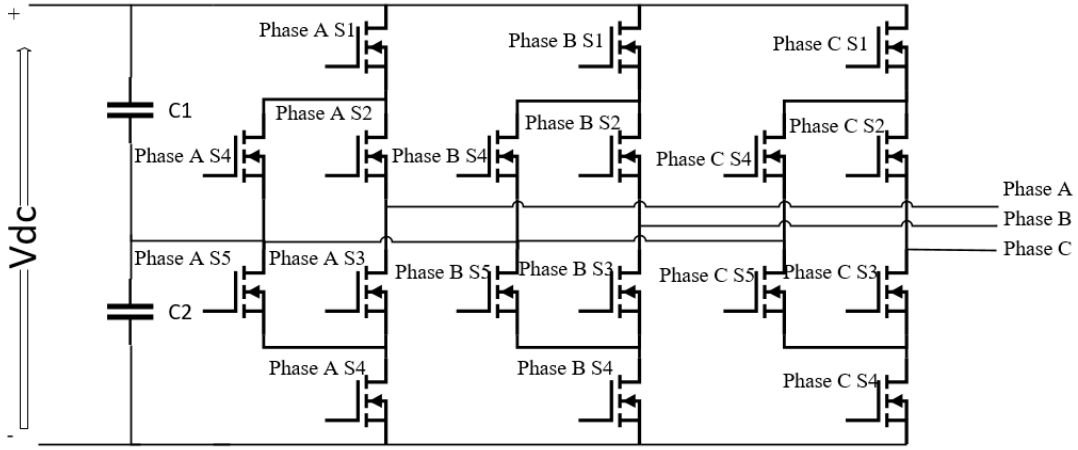
		Devices					
		Diode	SiC MOSFET	Si MOSFET	IGBT	GaN HEMT	JFET
Characteristic	Forward Voltage	Increases by 20-260% for all devices but GaAS which decreases by 20%	-	-	Decreases by 5-30%	-	-
	Gate-source threshold voltage	-	Increases by 50%	Increases by 50%	Increases by 20%	Range from: -35% to +15%	Not mentioned in the reviewed literature
	On-state resistance	Decrease for (20-70%): Silicon diode MBRS Schottky ES2A Superfast Increased for (20-80%) Silicon Ultrafast Silicon Schottky Cree SiC	Increases by 300%	Decreases by 80-95%	Decreases by 30-70%	Decreases by 80-90%	Decreases (the exact amounts not mentioned in the reviewed literature)
	Breakdown Voltage	Increased by 5% SiC Schottky Cree SiC ES2A Superfast Decreased by 20% MBRS Schottky Ultrafast Diode Silicon Schottky	Decreases by 20%	Decreases by 15-35%	Decreases by 20-70%	0%	Sparse data
	Switching Time	Reverse recovery time decreases by 30%	Sparse data	Rise and fall time decrease by 60%	Decrease by 60-80%	Lower switching losses (Not specified in literature)	Sparse data

Cryogenic power electronic

Comparison beetwen different multilevel converter

Type of converter	Advantages	Disadvantages
2L-VSI	-Simple control -Small number of switches	-Switches need to have a large breakdown voltage -Large THD -Efficiency lower than other converters
3L-NPC	-Highest efficiency -Low THD	-Complicated control -Unequal loss distribution
3L-ANPC	-Highest efficiency -Low THD	-Complicated control
4L-NPC	-High efficiency	-A large number of series components, lower efficiency
3L-FLC	-Small filter is required at the output -High efficiency	-Complicated control
9L-CHB	-Good fault ride-through capability -Modular -High efficiency	-Complicated control

ANPC Converter proposed



Cryogenic power electronic

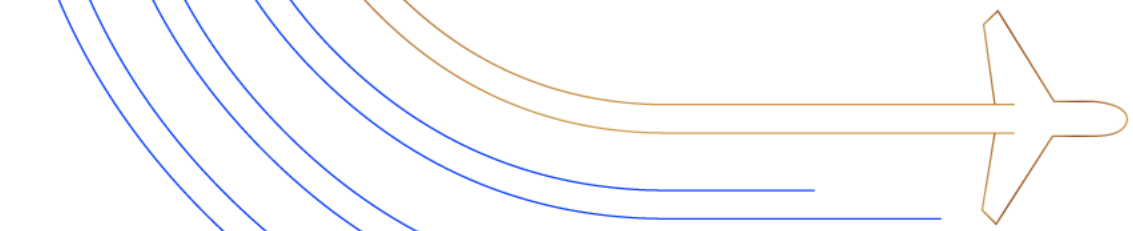
Synthesis of the main results for the cryogenic power electronics

- **Preliminary results (without cooling systems, EMI filter)**
  - INFINEON Manufacturer

Type	Device	Manufacturer	Weight (grams)	Total (kg)
IGBT(9 modules)	FF1800R17IP5BPSA1	INFINEON	1400/unit	12,6
Capacitors	Still under review	-	300-400/unit	0,4
Connections	Copper bar	-	650/module+ interconnections	5,0 (initial estimate)
Total	INFINEON (initial estimate)			18,0
Power to mass ratio				127 kW/kg

Type	Device	Manufacturer	Weight (grams)	Total (kg)
IGBT(9 modules)	5SNA 1600N170100 (Press pack)	ABB	820/unit	7,4
Capacitors	Still under review	-	300-400/unit	0,4
Connections	Copper bar	-	650/module+ interconnections	5,0 (initial estimate)
Total	ABB (initial estimate)			12,8
Power to mass ratio				180 kW/kg

CONCLUSION



To conclude

Overall goals

- Evaluation of the **benefits of superconductivity** technology for **HEP architecture**
- **Trade-off between liquid cooling and cryocooler** approach for superconductive component cooling

Activities

- **Superconducting machines**
  - SOA and study of superconducting machine topology and comparison between liquid cooling and cryocooler cooling
  - Pre-design of superconducting motors and generators taking into account the coupling to a propulsive (fan, propeller) and a mechanic power generating element (turbines) respectively

- **Cryogenic power electronics**
  - Study on the impact and advantage of cryogenic temperatures on power electronics

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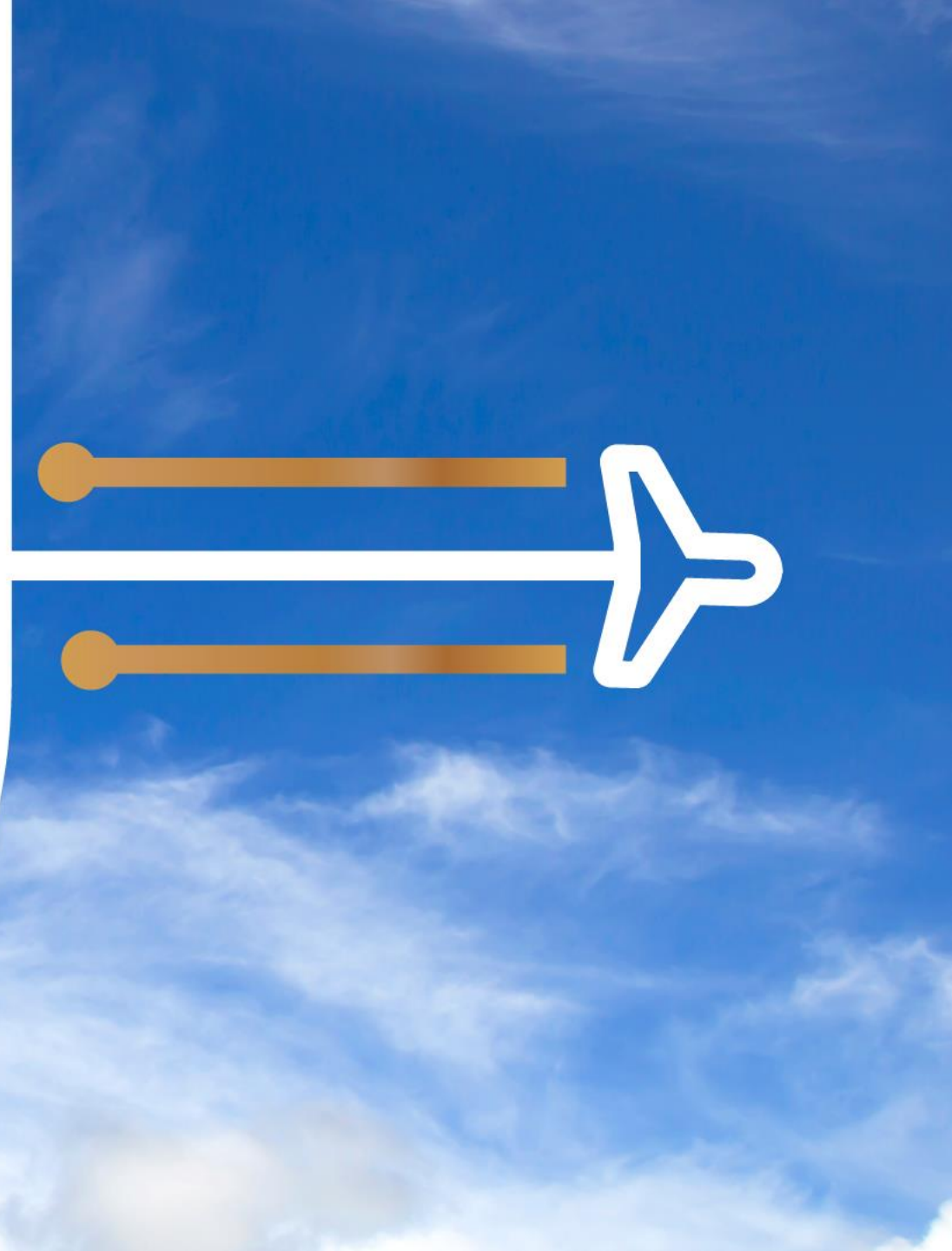

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