EDS Partner List

Partners full name	Partners short name
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Executive Summary:

Temes main responsibility within the BESTT consortium was the development an construction or the Central Cooling Unit (CCU), the R245FA Cooling unit for the heater supply, the High Current Power Supply and related printed circuit boards. Furthermore Temes was responsible to design the ACC components: High current / High Energy Density Heating Elements along with a new connector system.

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ABBREVIATIONS

a/c	Aircraft
ACARE	Advisory Council for Aeronautics Research in Europe
CSJU	Clean Sky Joint Undertaking
DoW	Description of Work
ED	Eco-Design
EDS	Eco-Design for Systems
BESTT	Bench Systems for Ground Thermal Tests
FHG IBP	Fraunhofer Institut für Bauphysik Holzkirchen / Valley
GAP	Grant Agreement for Partners
IA	Implementation Agreement
PCO	Project Coordinator (Consortium)
PO	Project Officer
TM	Topic Manager
TRL	Technology Readiness Level
WP, WPL	Work Package, Work Package Leader
ACC	Aircraft Calorimeter
CCU, CU	Central Cooling Unit, Cooling Unit
COP	Coefficient of Performance
GWP	Global Warming Potential
HAZOP	Hazard and Operability Analysis
HD	Hochdruck (High Pressure)
KMM	Cooling machine module
MT	Mitteltemperatur (middle temperature)
ND	Niederdruck (low pressure)
ODP	Ozone Depletion Potential
TT	Tieftemperatur (low temperature)
TÜV	Technischer Überwachungsverein (German test authority of law)
Vd	Verdichter (Compressor)
ZÜS	Zugelassene Überwachungsstelle

1 Introduction

An **aircraft calorimeter (ACC)** has been developed, providing a test chamber which can be

– heated up to 120 °C

– cooled down to -55 °C

Additionally, the internal test chamber air pressure can be adjusted between plus and minus 1 bar, differential to reference pressure.

The provided heating and cooling capacity allows testing even large aircraft parts and equipments.
Temperature gradients up to 100 K / min can be achieved.

Purpose of the ACC	**Providing the capability to expose materials of rapid temperature changes under high altitude conditions.**
ACC location:	Fraunhofer Institut für Bauphysik, Holzkirchen, Germany
Equipment developer:	TEMES Engineering GmbH, Warngau, Germany

2 Temes Workpages Overview

The ACC heating system and the three sub systems provided by TEMES:

CCU

The CCU = Central Cooling Unit comprises two cooling units (CU), working in parallel. Each cooling unit is equipped with

- four cooling machine modules
- one cooling oil storage vessel, filled with 1.700 l oil. The vessel is fed by the four cooling machine modules. Purpose of the oil: Providing high peak cooling capacity when changing the chamber temperature status from hot to cold.

A further vessel is used as expansion tank.

Electrical Heating System

The electrical heating system comprises the

- power converters and the power control system, both located in the Power Control Rack
- heating resistors

Max. heating power is > 100 kW.

Heater Supply Cooling Unit

The heat sinks of the power converter modules are water cooled. The waste heat is dissipated by the Heater Supply Cooling Unit, using refrigerant R245fa. Finally, the R245fa Cooling Unit transfers its waste heat to the facility's re-cooling system.

3 System Components

3.1 Central cooling unit (CCU)

Cooling machine module KM507

Each cooling machine module KMM507 provides a refrigerating capacity of 5 kW at -65 °C. As refrigerant R507 is used allowing this low temperature.

Cooling unit CU: 4 x KM507

Four modules KMM507 are mounted on a common frame and working in parallel, providing max. refrigerating capacity of 20 kW at -65 °C. The modules cool the cooling oil which is stored in the cooling oil pressure vessel. This arrangement forms the cooling unit (CU).

Central cooling unit (CCU): 2 x cooling unit CU

Two cooling units CU form the central cooling unit (CCU). The CCU provides max. refrigerating capacity of 40 kW at -65 °C. For safety reasons (environmental pollution) the CCU is located within a safety pan. The pan is dimensioned for the complete amount of cooling oil.

Cooling oil storage vessel

The cooling oil vessel has a capacity of appr. 1.700 l. The cooling oil works as cold storage.

Expansion vessel

The expansion vessel compensates works as compensation volume which is required due to the different volumes of the cooling oil, depending on its temperature.

3.2 Cooling unit

In compliance to the ongoing change management needs through the integration phase until April 2014, because not all connecting systems (e.g. ACC designs and T23 compartment) could be finalized and accepted with the FHG IBP and the BESTT consortium in a short time range (until April 2014), Temes had to change in different steps the scheduling, workload and work flow for the CCU system as well as the documentation (see picture below, as one point in the change management, e.g. CDR documentation).

The Central Cooling Unit (CCU) was successfully integrated in the FHG Test field and completely checked by 2 different external test authorities:

- TÜV Nord Essen checked all electrical realization works and the electrical definition files and drawings
- TÜV Süd “safety department” Munich defines in a HAZOP-Meeting and Report to all safety issues
- TÜV Süd “department for cooling system and conformity” Munich checked all realization works and safety reports in a step-by-step-reporting including the reporting to the results through the HAZOP-Meeting.

The Central Cooling Unit was successfully integrated in the FHG IBP area and there Benches and completely accepted from the German Test Authorities as well by step-by-step reporting’s.

3.2.1 Cooling oil

The CCU uses Therminol D12 a cold storage medium. Appr. 4.600 l cooling oil are used.

3.2.2 Refrigerant

The Central Cooling Unit uses R507 as refrigerant.
This refrigerant is suitable for temperatures down to -75 °C.

Thermophysical properties of refrigerants: R507

General:	
Composition	R125/R143a (50/50)
Family	HFC
Main application fields (in compliance with the legislation in force)	Industrial & commercial refrigeration
Molar mass	98,9 kg/kmol

Thermophysical properties:	
Normal boiling point (at 0.1013 MPa)	–47,1°C
Critical temperature	70,8°C
Critical pressure	3,72 MPa

Properties at 0℃ (at saturation)*			
	Unit (SI)	Liquid	Vapour
Pressure	MPa	0,63	0,63
Specific volume	dm^3/kg	0,86	30,89
Specific heat capacity • at constant pressure • at constant volume	 kJ/(kg K) kJ/(kg K)	 1,37 0,87	 1,02 0,82
Viscosity	10^{-6} Pa s	175,88	11,07
Thermal conductivity	W/(m K)	0,077	0,013
Surface tension	N/m	0,007	
Heat of vaporization	kJ/kg	161,5	

* These data are derived from the brochure Thermodynamic and physical Properties of R507 published by the IIR. You can order it on line.

Environmental properties:	
ODP (R11=1)	0
GWP (CO2=1)	3300

The GWP used as a reference here is the GWP of CO2 over an integration period of 100 years.

Safety groupe: A1

Unique selling points (USPs) of the Central Cooling Unit

Components of the CCU

1.) The six-cylindrical compressor machine type K813H / S6F-30.2Y from Bitzer GmbH is the first ever built two-stage semi-hermetic reciprocating compressor unit for R507a with an evaporation temperature of -72° C at a cooling capacity up to 5.84 kW. According to the datasheet Bitzer, the use was so far up to - 65 ° C evaporation temperature possible.

2.) For this new refrigeration system with R507a at an evaporation temperature of -72°C @> 5 kW was from Honeywell, a new expansion valve for refrigeration circuit developed.

3.) As part of the prototype development with the company CAM GmbH has the refrigeration system engineer Hr. Bäumler (CAM) in coordination with Frigotechnik / Bitzer and Honeywell first new principle successfully implemented for suction superheat and liquid subcooling.
The patent application for this purpose is reviewed by CAM and Temes.

Parameters of the refrigerant

The refrigerant used for this integrated 2 stage cascade refrigeration R507a was selected, because of:

1.) The refrigerant R507A is an alternative refrigerant to replace the cryogenic refrigerant R22 (from 01/01/2015 no longer allowed). It is the well-known refrigerant R404a very similar, but offers several advantages on the system side.

2.) Because of the azeotropic mixture refrigerant R507a refrigerant mixture over the zoetrope R404a behave the components of R507a (refrigerant R134a and R125 as a new chemical substance, especially in the transitional phases in Area of the condensation phase and boiling phase.

3.) In zoetrope cold mixtures (such as R404a) cook the individual components of R404a (refrigerant R143a, R125 and R134a) successively from the refrigerant R404a in the Transition phases from. This leads to a temperature glide, which in the specific case of integrated refrigerant cascade, as provided in the refrigeration system CCU BESTT to a complex system engineering leads.

4.) R507a R404a has over a higher cooling efficiency, a smaller ODP, a significantly higher coefficient of performance and no glide at approximately the same GWP. so that can provide better cooling capacity than comparable the R507A refrigeration system R404a refrigeration system.

5.) The refrigerant R507a is in the EU Regulation and ChemKlimaschutzV UBA in the category A1 (non-combustible, non-toxic) classified. Thus, no special System monitoring required for the operation of the refrigeration system.

4 System Components

The ACC heater is used to rapidly heat up the air in the ACC test chamber. A voltage converter provides up to 120 kW electrical power for the heater. The power electronics components of the voltage converter are mounted on water cooled heat sinks. The cooling water absorbs the waste heat dissipated by the power electronics.

The 2.5-m³ storage tank works as a heat buffer.

To cool the water in the storage tank a 25-kW cooling unit (refrigerant: R245fa) is provided.
The R245fa unit transfers the heat to the test facility's recooling circuit, dissipating the heat to the environmental air using a cooling tower.

The R245fa cooling unit including the tank was delivered to the FHG IBP and is ready for integration to the FHG IBP environment since Sept. 2013, but is isn’t foreseen to integrate this in this program yet, because of the budget needs at BESTT-program.

5 R245fa cooling unit for heater supply

This cooling unit is used to cool the water of the 2.500-l storage tank. The water absorbs the heat dissipated by the heat sinks of the high current power supply for the ACC heater.
The future advantages of the R245fa cooling units for cooling properties e.g. FUEL CELL systems including high power electronics for aeronautics and special application we shown within this project.

6 High current power supply

6.1 Technical data

High-current power rack	Fully modular, fully digital 24-bit controlled high-current system
Input	400 V AC3
Fuse	200 A
Output	max. 2.700 A@50 V DC
Max. Output Voltage (Hardware)	72 V DC
Max. Output Current (Hardware):	2.000 A
Module equipment	3 high current modules in parallel
Size (L x B x H)	800 mm x 1.000 mm x 2.400 mm
Weight	1.250 kg
Power module	
Max. output current	1.250 A
Max. voltage	400 V DC
Voltage ripple	<100 mV_{P-P}
Current ripple	<100 ppm_{P-P}
Control	Current controlled output for electrical heating system of the ACC
Cooling	Water cooled 60 l/min flow at min. 2,25 bar
Inlet temperature	min. 18 °C - optimal: >21 bis 30 °C
Heater loads in the ACC	5 groups in parallel, each group (0,14 Ohm) with 25 steel-grid resistors (each 5,6 mOhm) and 12,5 kW continuous load at 250 A, located in the bottom area of the ACC. Overload power condition with 400 A each group is allowed for 10 sec.

6.2 Short description

The heater supply rack is capable to supply 2.700 A max. at 50 V max. Following main components are built in:

F10: Fuses	The three phase input voltage lines are wired to the three phase fuse separator F10. F10 allows separating the input voltage from the rack by means of a handle which lifts off the fuses from its holders.
Q1: Line protection	Q10 is a line protection switch which opens in case of a short circuit or after long-time overload.
A1: EMI	A1 is the input EMI filter.
Thyristor section	Each phase is wired via a double thyristor allowing controlling the intermediate circuit voltage by use of phase angle control.
T1, T2: 12-pulse transformers	The transformers transform the input voltage and provide galvanic separation. One transformer is a wye-wye transformer, the other one a delta-star transformer.
V1,V2,V3 and	These double diodes are wired as two B6 rectifier bridges. One bridge input is

V4,V5, V6: Double diodes	connected to the secondary of T1, the other to the secondary of T2. The B6 rectifier bridge outputs are wired in parallel. Due to the phase shift between the transformer output voltages the generated DC voltage has low ripple.
U1, U2: Current sensors	Two Hall sensors (LEM) measure the rectifier output currents for control purposes.
Intermediate circuit	L1, L2 and capacitor module A21 form a filter. The filter smoothes and stabilizes the intermediate circuit voltage.
A2, A3: Step down choppers	Two step-down chopper modules are fed by the intermediate circuit voltage and work in parallel. The rack is equipped with two TEMES high current buck converter modules TEM-1027. Each module is capable to supply 1250 A at 74 V max. output voltage. The power electronics components of the modules are mounted on water cooled heat sinks. Cooling is provided by the R245fa cooling machine.
U2: Output current sensor	The total rack output current (2.000 A max.) is measured by sensor U3.

6.3 Step down chopper for heater supply

The step down chopper is located in the heater supply rack.

Four double IGBT modules V1 to V4 are working in interleaved mode to switch the input voltage to the output. Only the upper IGBT's are switched when working for the heating.

Each part current is measured by its own current sensor (B1 to B4). Additionally, the total current is measured by sensor B5.

7 Boards

The new developed and realized high current power supply was tested and fully operable and fulfilled all defined specification points.

The high current power supply is ready for integration to the FHG IBP area, but it isn't foreseen to integrate yet, because of the financial situation in the BESTT-program, and the ship at place at Temes is agreed with the Topic Manager.

8 ACC components by TEMES

(ACC not scope of supply of TEMES)

8.1 High Current high energy density heating elements for ACC Heating walls:

Advantages: 180 to 200kWs energy storage versus 50 to 70 kWs state of the art

The 5 heating units are ready for integration to the FHG IBP area, but it isn't foreseen to integrate yet, because of the financial situation in the BESTT-program, and the ship at place at Temes is agreed with the Topic Manager.

<u>New connector system for ACC test equipment:</u>

One of the biggest problems in state-of-the-art-power electronic system is the connection between power electronic modules and the environment or the connection between systems.

So, a unique connector system was designed and developed to uphold the parameters for aeronautic equipment and power electronic modules according to the electrical net specifications as well as the mechanical and environmental specifications.

Advantages/target:

1. weight reducing up to 50-60% vs. state of the art, readiness and operability for aeronautic applications
2. High-current contacts
3. IP69
4. High-temperature operability vs. high current and/or high voltage possibilities
5. Loss reducing contacts vs. readiness for aeronautic applications

These finalized designs for the connectors were build as first Prototypes. These Prototypes were fulfilling all electric specification points, but not all Environmental and Weight Needs.

So in the construction phase these points were defined and prototyped in a hybrid manufacturing process with milling and injection molding machines for the first Prototypes.

Through the construction phase of the new designed connectors a lot of problems occur through structure complexity in the connectors and their state-of-the-art-production of connectors.

We find out that the matrix tools for the injection molding machines has to be more flexible, which increases the costs per tool up to 30.000,- Euro per Tool (6 tools are needed), in sum 180 TEUR. So it is not possible to realize all connector types we want to produce for the ACC integration.

So, we discussed these facts, also with our other Connector Suppliers, but without a solution which fulfilled our complete specifications.

So we had to reduce our parameters and targets, and could produce first pre-series connectors, to finish this milestone.

Potential future Impact:

Central Cooling Unit at -65°C:

In future test bench areas, in compliance with new aeronautic standards, it will be necessary to cool down environments and test configurations below – 55°C, so there is a very high interest from test facilities for new cooling systems, which are able to convert very low temperatures with compressor-based machine systems, like the CCU.

R245fa cooling unit:

The future advantages of the R245fa cooling units for cooling properties e.g. FUEL CELL systems including high power electronics for aeronautics and special application we shown within this project.

High current high power system as heating system:

The future advantages of the high current power systems are very sufficient for heating applications in future test bench areas as well as converter systems in FUEL CELL programs for aeronautics and special application we shown within this project.

New connector units for high power systems:

First prototypes very build, but for the ACC integration these connectors are not feasible.

It is necessary in a further development program to invest in high-grade flexible tools to produce connector sets, which are convenient and next to a series connector sets in a state-of-the-art-production line, without any special tooling or separate hybrid production process.