Integration simplification of capillary driven heat transport systems

Executive Summary Report

Contract Number 4000129516/19/NL/KML

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Introduction - Context

Currently, the consortium EHP and ADS Mechanical Design Office designs, qualifies and tests the hardware that is installed on spacecraft by satellite prime based on a procedure written by the CDHTS supplier (for LHP² constraints) and the satellite prime (for S/C configuration and constraints). In Airbus Defence and space (ADS), the LHP manufacturing, filling and test are performed in EHP and then the hardware is transported and integrated in ADS AIT thanks to an important MGSE and flexible lines. The current EHP LHP AIV process has been the results of 20 years of lesson learn.

The LHP MAIT keys operations are the following:

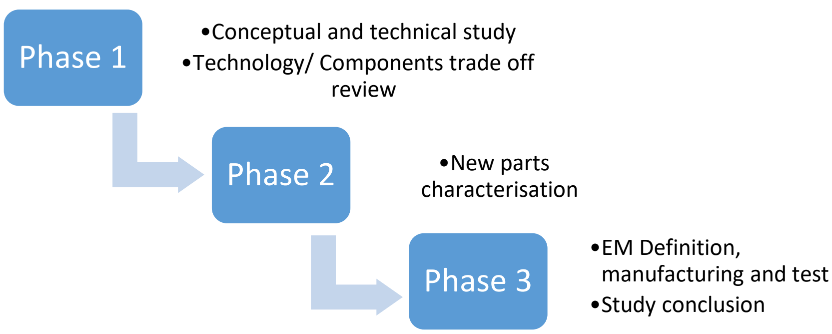
- LHP assembly using welding and/or new connectors
- Workmanship test including a cold proof in azote and with a helium test on each connections allowing detecting a leak down to 10-8 atm.cc/sec.
- LHP cleaning including a vacuum bake-out: the aim of this operation is to de-gas the LHP internally at hot temperature under vacuum for a long duration to prevent the formation of NCG. This operation has been developed to ensure the evaporator cleaning which is the most difficult part to clean in an LHP.
- Burn-in: the aim is to accelerate the creation of NCG due to impurities and to interaction between metal and hot two-phase ammonia. Critical activity to generate NCG and particularly in the evaporator.
- Ammonia purge and filling: the ammonia is purged to remove NCG.
- Filling tube pinching and welding with dye-penetrant inspection and X rays validation of the welding or the use of a new part with dedicating control.
- NH3 hot proof test with associated NH3 leak test on the filling tube: this allow validating only the pinching as no leak tests is done on the other welds and/or connection.
- Performance tests on the LHP if needed: with TVAC test in the current process
- Delivery of the LHP and integration on the S/C

To meet customer's needs, new payloads are needed such as digital payload. These payloads reshape totally the accommodation of S/Cs and thus the philosophy of its thermal control. The new dissipative units are more numerous and often far away from cold source. This represents a new constraint for the design of future LHP product as the pipework is foreseen to be more complex to link an evaporator which would likely be inside the S/C toward the condenser which would likely be on the exterior side of the S/C.

The historic MAIT flow is not adapted to such applications. The design of the LHP routings and the needed MGSEs would indeed be very complex to ensure compatibility with a complex integration sequence of an LHP as a single block. The cost of such product is then foreseen to increase significantly, assuming it is still possible to design an LHP coping with all the constraints.

The simplified approach aims at tackling theses pain point offering new solutions providing more flexibility for the LHP design and for its validation, reducing the overall costs by easing the handling and the integration of the LHP and optimising the planning.

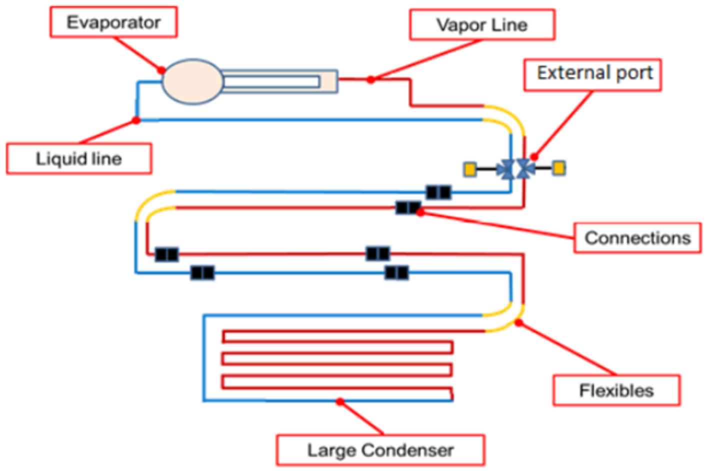
The study is discretized into 3 different phases.



During Phase 1 the following new LHP architecture have been proposed to ease integration sequence. It consists in splitting the LHP into 3 different functional unit:

- ➔ Evaporator
- ➔ Piping assembly
- ➔ Condenser assembly

LHP require working fluid to operate. To ease AIT activity, a initial filling of the evaporator by the supplier and an isolation of the fluid in the Evaporator has been selected.



A review of all the LHP designs within ADS has been performed to compare the mass of ammonia needed per LHP vs the maximum mass of liquid ammonia that could be accommodated within the LHP reservoir @ 40°C.

Program	Mass of NH_3 Equivalent liquid volume @ 40°C	Evaporator volume (cc)	Evaporator allows to accommodate the LHP mass of NH_3
TELECOM 1 Plateform 1	170g – 293.3cc@40°C	297.7cc	YES
TELECOM 1 Plateform 2	129.5g – 223.4cc@40°C	297.7cc	YES
DPR NEO	438.5g – 756.8cc@40°C	794.6cc	YES
DPR ONESAT Tx	612g – 1056cc@40°C	1230cc	YES
TELECOM 2	287.4g - 496cc@40°C	522cc	YES
Observation S/C	**62.6g – 108cc@40°C (BUS1)** **62.9g – 108.6cc@40°C (BUS2)** **42.6g – 73.5cc@40°C (BUS 3)**	159.8cc 143.5cc 119.1cc	YES
Atlid / Observation2	11.4g – 19.6cc@40°C	17.7 cc	NO

In most of the cases the compensation chamber volume is sufficient to accommodate le total mass of NH3 with an environment @ 40°C except for mini-LHP.

As for mini-LHP the number of applications identified is very limited and the reservoir volume too small for NH3 storage, for this R&D it is preferred to consider on NH3 Medium-LHP application where a lot of application are identified for the future.

The conclusions for Medium-LHP are foreseen to be applicable for other two-phase system such as mechanical pump loop (MPL).

The new architecture shall respect the following main requirements:

Ports

Filling, purging and test port may be present in the architecture.
As for CPS dedicated areas on the side of the SC will be allocated to previous port to allow baseline AIV and at a late stage of the built.

Industrialization

Sub-assembly shall be available at different time of the SC built sequence.
Pipework section sub-assembly shall be available at the beginning of the SC assembly to allow early integration
Sub-assembly shall be interchangeable with spares.

LHP filling preparations in ADS AIT

Cleaning and testing shall not impose to reach LHP temperature environment above to 30°C.
Proof testing shall be allowed to be compatible with ADS clean room AIT

LHP Filling on SC

As a mandatory activity, the LHP filling:
- safety measures shall be compatible with ADS clean room AIT
- shall be compatible with parallel SC integration activities

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Connection to dummy radiator and evaporator

For SC or hot source testing, the LHP shall allow connecting:
- The flight evaporator sub-assembly to a dummy pipework and/or condenser
- The flight condenser (and pipework) to a dummy pipework and/or evaporator

Purging

Purging is a mandatory activity in case of:
- Anomaly requiring LHP disassembly
- Connection to dummy evaporator and condenser

As they could be performed in dedicated AIT areas, and isolation of the SC could be allowed.

To ease performing fluidic activities in CR environment and in S/C vicinity, a FGSE shall be developed gathering all needed functionalities. Theses functionalities are summarised hereafter:

FGSE Function	Operations
Pressurizing	Wormanship tests
Vacuum capabilities	Condensor and pipework cleaning
Inert gaz flushing	Cleaning during connection operation to avoid particles contamination (if needed)
Purging	Back-up operation
Filling	Back-up operation

The analysis of the requirements on the new LHP architecture led to the definitions of the component's requirements summarized hereafter. These requirements have permitted to select the on the shelf components better suited to the application among the wide range of components existing.

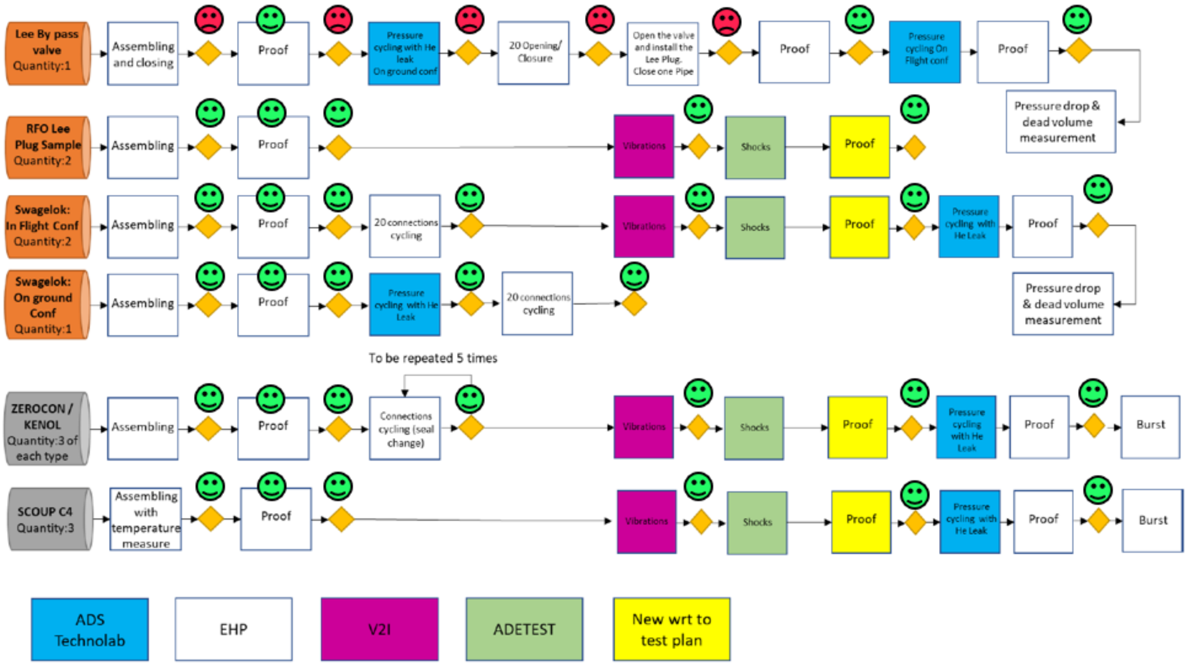
	Connec-tors	Evapo isolation valve	Fill&drain valve	Caps
Lifetime 7years On-ground storage and 15y in-flight	X	X	X	6 months
External leak 3.10-8atm.cc/sec	X	X	X	NA
Internal leak in atm.cc/sec	NA	10-5	NA	10-7
Pressure : proof at 69bars	X	X	X	15bars
Temperature non-operational -40°C/+85°C	X	X	X	0-50°C
LHP new parts maximal pressure drop : DP=1000Pa at 0,84g/s gas ammonia at 40 bars	X	X	NA	NA
External ports pressure drop : DP=1,5bars at 140 atm.L/min gas Argon at 5 bars – Cv>0,18	NA	NA	X	NA
Materials : stainless steel, PTFE, PE, EPDM & FFKM	X	X	X	NA
Pipe diameter 2.155/3.175mm, 3.5/4.5mm, 4/5mm	X	X	X	X
Mass including supporting structure	40g	40g	100g	NA
Integration volume : 50 mm X 50mm X 50 mm for tools and connections and 100mm X 100mm X 100m for access	X	NA	NA	X
Mounting flexibility	X	NA	NA	NA

NA Non Applicable

Existing On-The-Shelf components (COTS) full filling above requirements have then been traded off to selected those compatible with previous requirements. The tradeoff criterions & weight are given below:

	CRITERIAS	*Connectors weight*	*Valve Weight*	*Final tube closing*
LHP performance impact	Pressure drops	4	3	1
	Risk of NCG generation	4	2	2
	Particles generation	2	2	2
	Amonia lost		2	2
	Dead volume	2	1	2
	Sensitivity to thermo-elastic	1	1	1
	Internal Leak Rate		2	
	External Leak Rate	6	4	4
	Mass impact	4	3	4
Sub-total		23	20	18
Accommodation	Volume and integration volume required	2	1	1
Ease to assemble/dismount in EHP facilities	Ease to connect (connector) or easy to close (valves & filling tube)	2	1	1
	Operator qualification	1		
	Control	1	1	1
	robustness of installation process	2	1	1
	Ease to open/dismount (tools and operations constraints)	1		
	Number of connexion/deconnexion possible	1		
	Activities duration	1		
Sub-total		11	4	4
Compatibility with transportation & storage		1	1	
Ease to use in ADS AIT	Alignment, connector bolting torque	1		
	Flexibility offered or need for (pig tails, U shape, unsupported pipe…)	1		
	Ease to assemble (connector) or easy to open (evapo valves - Lockable System) or easy to close (filling tube)	2	2	2
	Control	1	1	1
	Operator qualification	1		1
	Activities duration	2	1	1
	Risk for S/C	2		1
	Risk for operators	1		1
	Safety constraints	1		1
Sub-total		13	5	8
Industrialisation		2	2	2
In-Flight experience (1=none 2=yes but no in ADS 3=ADS experience)		2	2	2
On-the-Shell product (1=need important development 2=delta qualification only 3=already qualify)		2	2	2
Total		53	35	36

The majority of solution selected through the trade-off have no flight heritage. To assess their compatibility with space environment, a relevant characterisation have been performed during Phase 2 according to the test sequence here after. The vast majority of components demonstrated robust design. Only the Lee By pass valve showed poor performances. Investigations showed that a misuse of the valve during the assembly was the root cause of the poor performances.



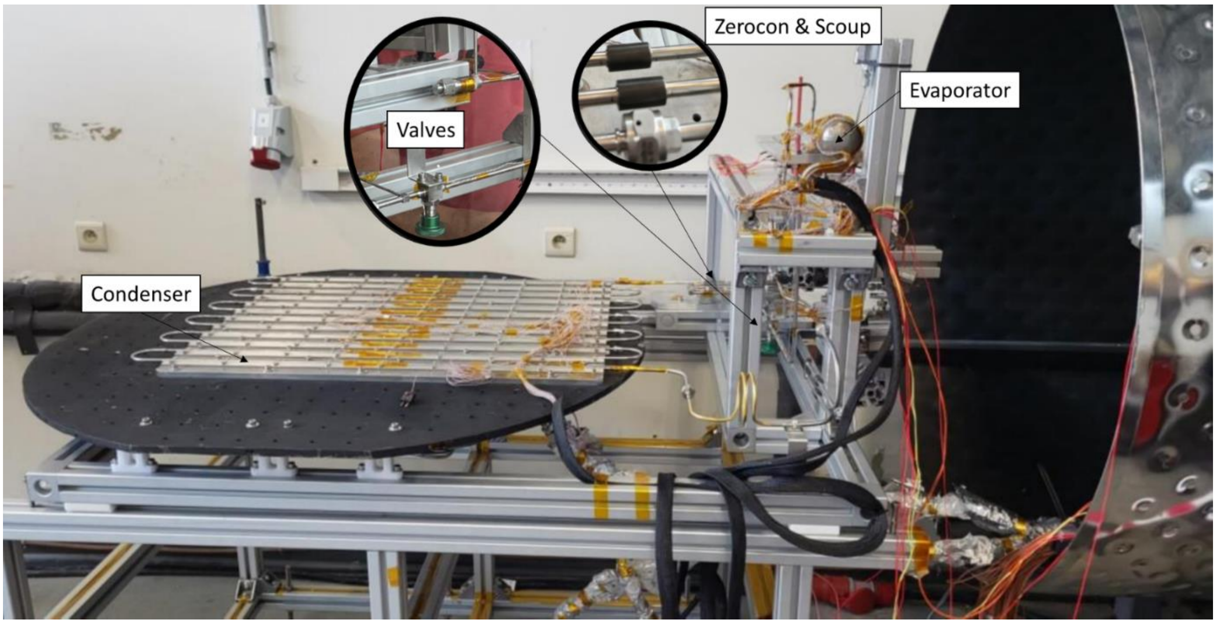
All components have thus demonstrated robust design. The Zerocon coupling and the Swagelok valve have then been selected has they were more convenient to use.

To validated the simplified integration philosophy, an EM has been manufactured implementing an LHP with the new architecture providing the ability to integrate each building block (evaporator, condenser, piping) independently. The objectives of this EM are to validate the new end-to-end process:

– Simulation of all critical operations (filling, purging, cleaning, vacuum, storage)
– Perform workmanship verification tests (Proof pressure test, He leak test and NH_3 proof and leak after final closure)

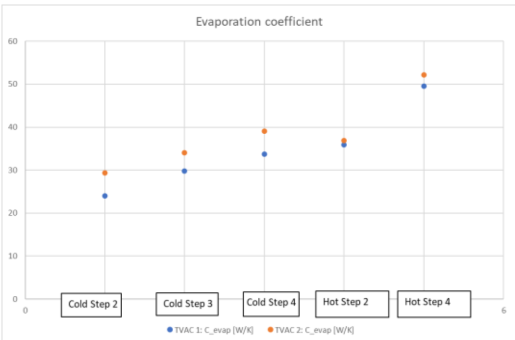
The EM will thus permit to validate the following aspects:

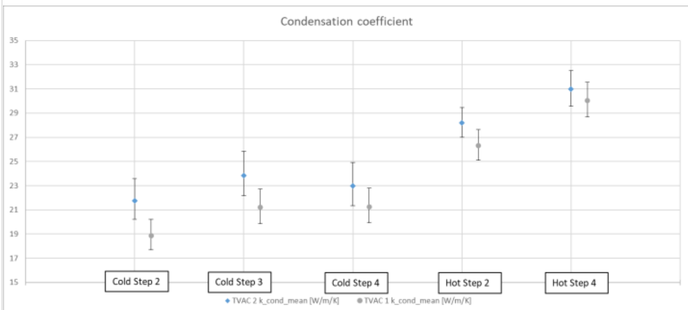
- The mounting and the complete thermal Bus performance;
- dismounting and mounting cycles (5)
- The LHP performances in vacuum chamber comparison to the initial ones
- The NCG formation after 5 mounting/dismounting.
- Proof pressure test and He leak test assumed after each disconnection/reconnection
- Loss of fluid measurement



EM Assembly

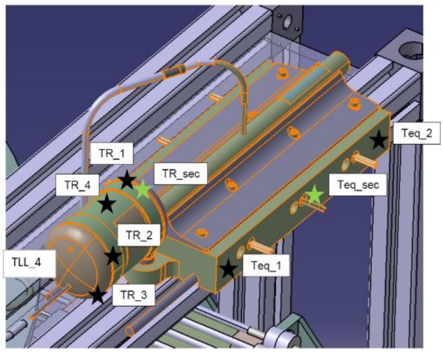
The performance of the LHP have been tested before dismounting and mounting cycles and after to validate that the simplified integration does not hinder LHP performances. Three analyses were performed to validate the LHP performances and no impacts have been measured on the LHP evaporation and condensation efficiency:



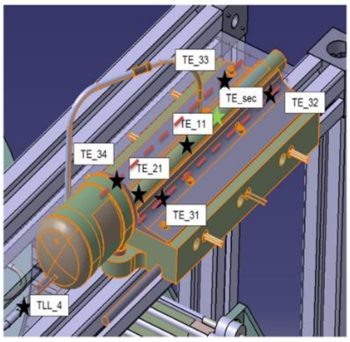


At first hand it seems that the LHP require more subcooling but deeper investigation show that the internal heat leak from the evaporator to the reservoir is equivalent for both TVAC.

	TVAC 1	TVAC2
	dT_sub [°C] TR4 – TLL4	dT_sub [°C] TR3 – TLL4
Cold Step 2	3,7	8,0
Cold Step 3	5,3	10,1
Cold Step 4	7,2	13,0
Hot Step 2	3,4	2,5
Hot Step 4	6,2	4,0

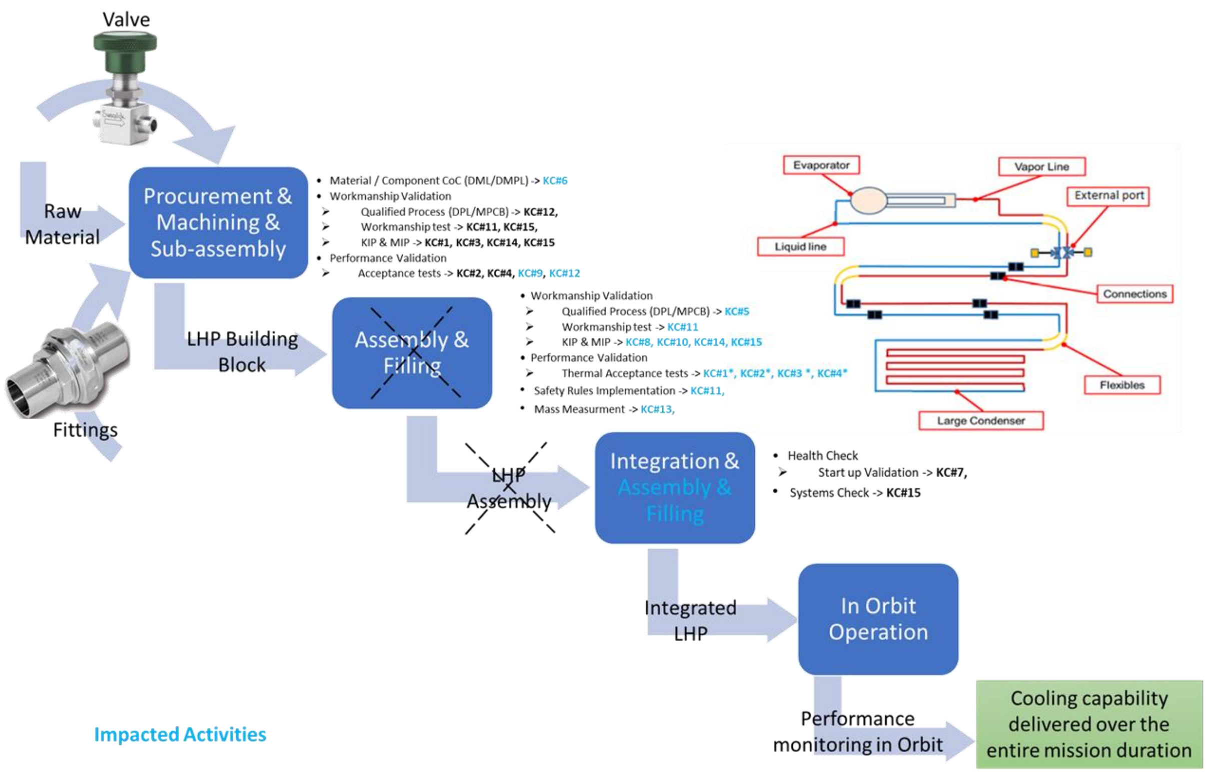


	TVAC 1	TVAC2
	dT_cav [°C] TR1 – TE21	dT_cav [°C] TR1 – TE21
Cold Step 2	1,1	0,7
Cold Step 3	1,9	1,1
Cold Step 4	2,8	1,7
Hot Step 2	0,2	0,2
Hot Step 4	0,4	0,4



A maturity level of TRL5 is achieved through this R&D. However, the usual LHP End to End validation plan related to the Key Characteristics (KC) listed hereafter is impacted by the new simplified integration philosophy.

	Topic		Topic
KC#1	Evaporator I/F performance	**KC#8**	Fluid Initial mass
KC#2	Evaporator C_Evap	**KC#9**	LHP Max flow rate
KC#3	Condenser Linear Conductance	**KC#10**	LHP Pressure losses
KC#4	Condenser Effective Length	**KC#11**	LHP Leak tightness
KC#5	LHP Filling	**KC#12**	LHP Mechanical Strength
KC#6	Material Compatibility with NH3	**KC#13**	LHP Mass
KC#7	LHP Start-up	**KC#14**	I/F position
		KC#15	Others System requirements



Some additional activities have thus been identified as necessary in order to implement the new simplified integration philosophy on S/C. The following WBS have been established for these activities: